DETECTOR RESEARCH SCHOOL

Semiconductor Detector Laboratory Exercise

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1 Introduction

The purpose of this exercise was to get familiar with silicon sensor diodes and the readout electronics needed to measure a signal from a radioactive source.

2 Theory

2.1 Silicon sensor

A diode made of lightly n-doped silicon with a heavily p-doped region at one side and a heavily n-doped region on the other can be used to detect charged particles and photons. However the silicon needs to be depleted from charge carriers. This is obtained by applying a reverse biasing voltage.

A charged particle or photon interacting with the silicon will produce electron-hole pairs which result in a pulse that can be measured by the readout electronics.

If the silicon diode is going to be used as a sensor, it is important to know the voltage needed to fully deplete it as well as the leakage current, since it will affect the performance of the readout electronics. These quantities can be measured in a clean room environment.

2.2 Equivalent Noise Charge

Another quantity that is essential for the performance is the Equivalent Noise Charge (ENC), which is the number of electrons one would have to collect from the silicon sensor in order to create a signal equivalent to the noise of the sensor. It is given by

$$\mathrm{ENC} = \frac{v_{\mathrm{RMS}}}{A} \cdot N_{\mathrm{electrons}} \tag{1}$$

where v_{RMS} is the root-mean-square noise and A is the amplitude of the output signal from the preamplifier. The number of electrons $N_{\mathrm{electrons}}$ is given by

$$N_{\mathrm{electrons}} = \frac{U_{\mathrm{cal}} \cdot C_{\mathrm{cal}}}{e} \tag{2}$$

where for this experiment $U_{\mathrm{cal}} = 6.9$ mV is the voltage of the calibration pulse, $C_{\mathrm{cal}} = 0.4$ pF is the calibration capacitance of the preamplifier and $e = 1.602 \cdot 10^{-19}$ C is the elementary charge. Thus $N_{\mathrm{electrons}} \approx 17250$.

3 Experimental setup

The equipment used in the first part of the exercise consists of a veroboard with a preamplifier, a power supply with two voltages, a square pulse generator and an oscilloscope.

Furthermore, a spectral amplifier and a pulse height analyser is used in the last part of the exercise.

A diagram of the preamplifier with the pins identified is shown in Figure 1. On the left side are three pins: one for grounding, one for the silicon sensor input and one for the calibration input. On the right side are four pins: Two for voltage input (-12 V and 12 V), one for the output signal and one for grounding. The blue, red and green wires are connected to the power supply.

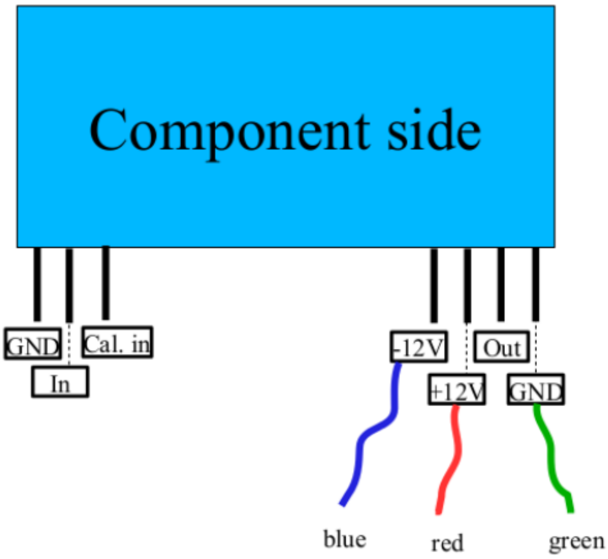


Figure 1: Layout of the preamplifier used in this experiment.

A 50Ω resistor is placed between the pulse generator and the calibration input to reduce the voltage of the calibration pulse. Moreover, a 100 nF capacitor is placed after the output from the preamplifier in order to remove the voltage offset.

Both the signal from the pulse generator and the output from the preamplifier is monitored with the oscilloscope. These pulses and the entire setup are shown in Figure 2.

The inside of the gray box is shown in Figure 3. It contains the veroboard with the preamplifier and a “creative corner”, which is where a low pass filter is build for the last part of the exercise.

The high voltage goes through the low pass filter before reaching the silicon sensor. The low pass filter consists of a resistor and a capacitor, which is shown in Figure 4.

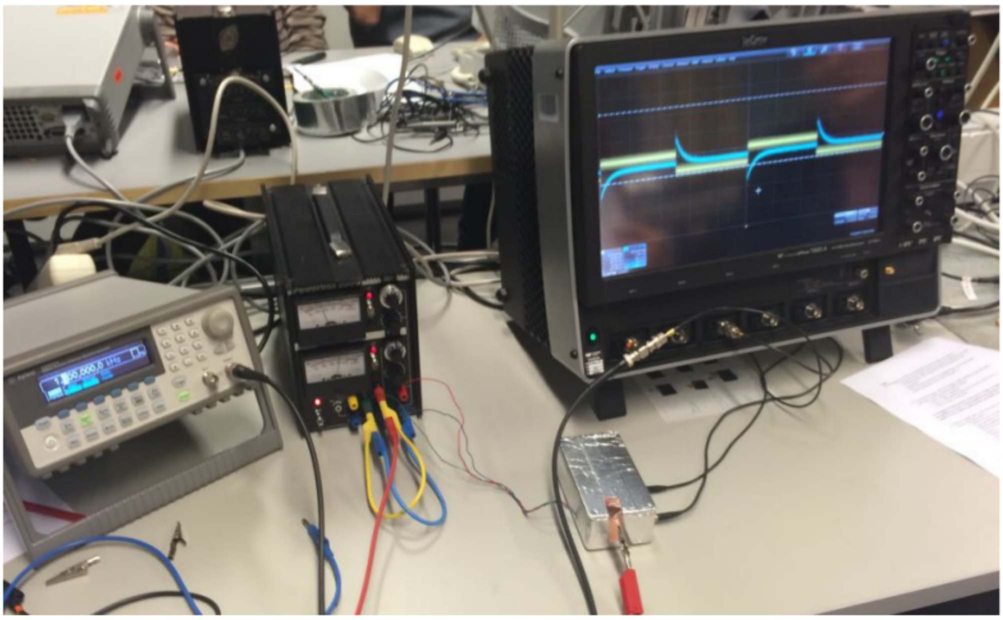


Figure 2: The setup for the first part of the exercise. On the oscilloscope are the signal from the pulse generator (yellow) and the preamplifier (blue) seen.

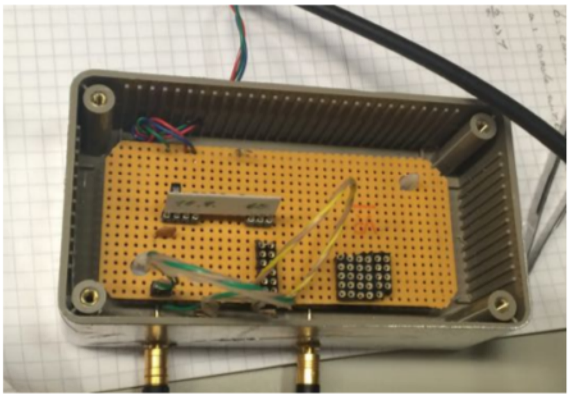


Figure 3: The veroboard with preamplifier and "creative corner".

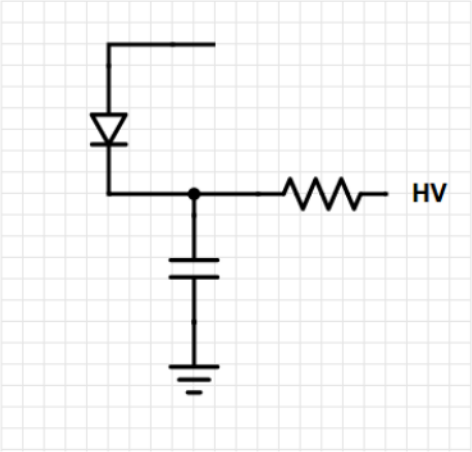


Figure 4: Schematic of the low pass filter.

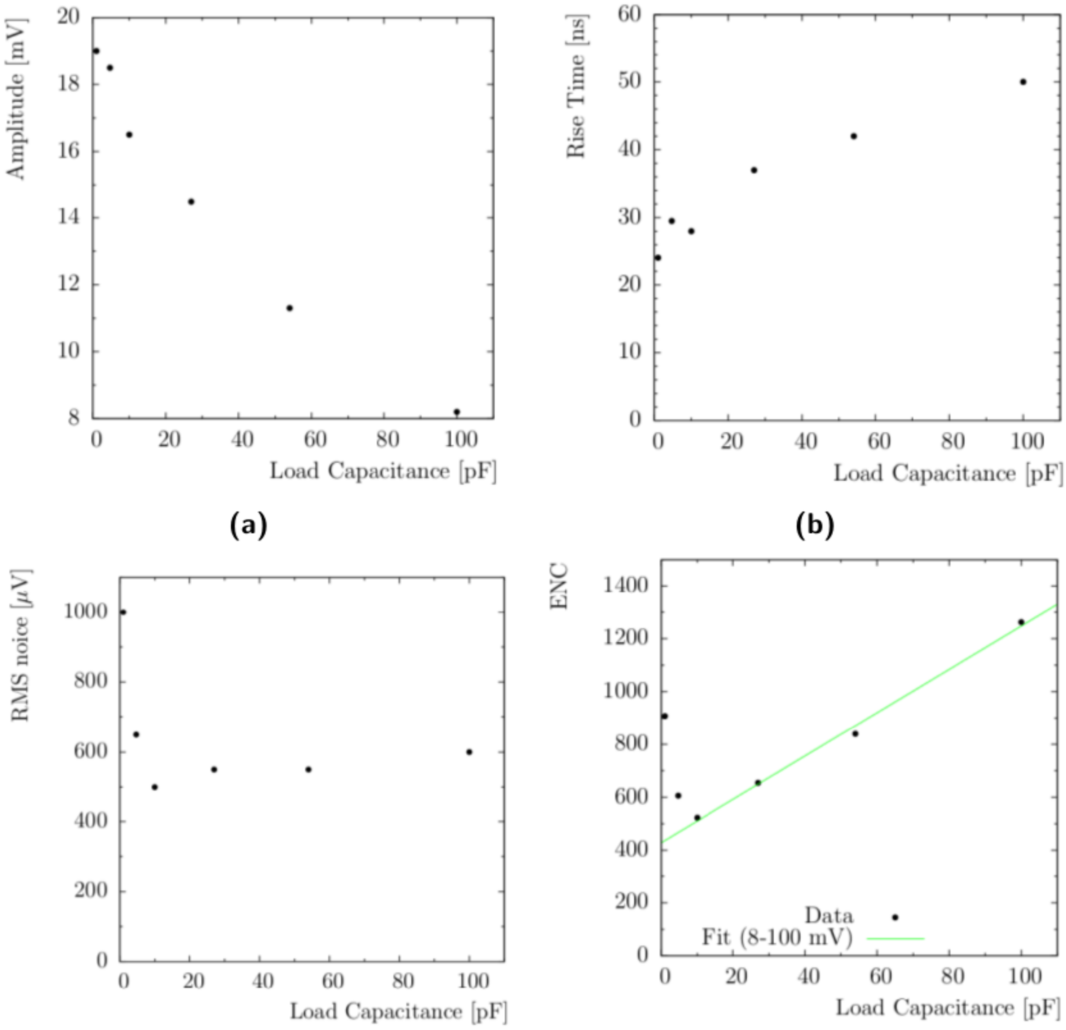
4 Results

4.1 Preamplifier Performance

In the first step of the experiment, the amplitude, rise time and noise of the preamplifier was measured for different load capacitors. The results are listed in Table 1 and illustrated in Figure 5a, 5b and 5c. In addition to that, the ENC for each capacitor was calculated by using equation 1 and is shown in Figure 5d. In order to obtain the pedestal noise N_{ped} and noise slope N_{slope}, a linear χ^2-fit was applied and give the parameter values:

$$N_{\text{slope}} = 8.2 \pm 0.4 \quad \text{and} \quad N_{\text{ped}} = 428.5 \pm 22.5.$$

Note that the RMS noise for 1 and 4.7 nF were neglected in this fit since their values differ significantly from the expected linear behaviour with respect to the load capacitance (see Figure 5d). We assume that the reason for this deviations are some kind of error in the measurment procedure and not of physical nature.



(a) **(b)**

(c) **(d)**

Figure 5: The measured amplitude (a), rise time (b), RMS noise (c) and the calculated ENC (d) over the load capacitance.

C_{load} [pF]	A [mV]	t_{rise} [ns]	v_{RMS} [μV]
1	19.0	24.0	1000
4.7	18.5	29.5	650
10	16.5	28.0	500
27	14.5	37.0	550
54	11.3	42.0	550
100	8.2	50.0	600

Table 1: The measured amplitude A, rise time t_{rise} and RMS noise v_{RMS} for different load capacitance C_{load}.

4.2 Calibration of the Preamplifier

In order to calibrate our preamplifier, we applied three test pulses with the voltage of 20, 40 and 60 mV for a 2 μs and 8 μs shaping time each. The calibration plots and fits are illustrated in Figure 6 and the measured values are shown in Table 2. The statistical errors of the input voltage are determined by the FWHM of a Gaussian fit.

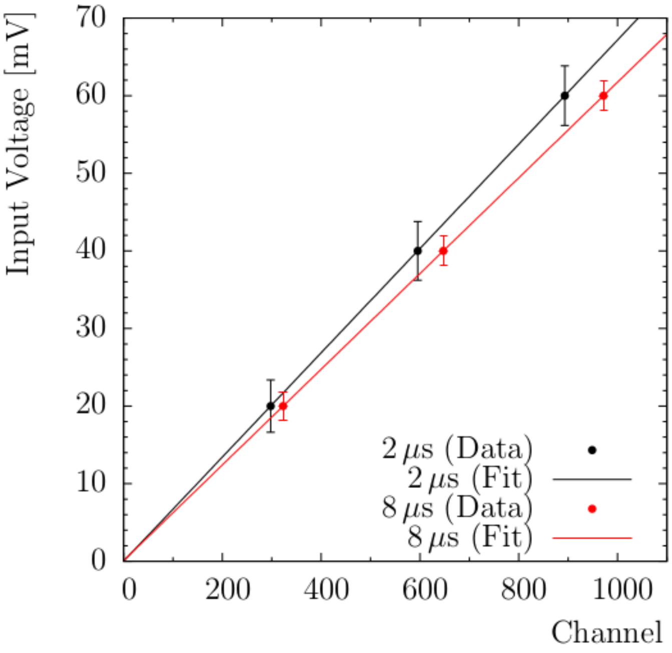
The parameters of the χ^2 fits, that are essential for the calibration, are given in Table 3.

shape time 2 μs		shape time 8 μs	
input voltage [mV]	channel	input voltage [mV]	channel
20.00 ± 3.37	297.83	20.00 ± 1.77	322.99
40.00 ± 3.78	595.55	40.00 ± 1.92	647.48
60.00 ± 3.84	893.25	60.00 ± 1.92	971.73

Table 2: The measured channels for an 1, 2 and 3 MIP used for the calibration of the preamplifier. The channel and the statistical error are obtained by using the mean value and FWHM of a Gaussian fit respectively.

shape time [μs]	intercept [10^{-2} mV]	gradient [10^{-2} mV/channel]
2	-0.82 ± 0.08	6.7179 ± 0.0002
8	8.3 ± 0.9	6.1657 ± 0.0002

Table 3: The parameters of the χ^2 fits for the shape times of 2 and 8 μs.



Nice plots. You could also extract the FWHM in ENC and compare with RMS ENC from previous measurement.

Figure 6: The input voltage over the measured channel used for the calibration of the preamplifier. The statistical error are given by the FWHM of a Gaussian fit.

4.3 Radiation Source

After the calibration of the preamplifier, the application of the semiconductor detector was attempted. However, due to a high level of noise and lack of time in order to search for its source(s), it was not possible to measure any signals of the radioactive sample.

You were unluckily at the table that gave consistently high noise (compared with the opposite table) :(

5 Discussion

Please have a look in G3 results that you can find in eg A.Burgman report eher you can find a nice AM spectrum.

By investigating the preamplifier using a pulse generator and an oscilloscope, we were able to maeasure the amplitude, rise time and RMS noise of different load capacitances from 1 up to 100 pF and to determine their ENC values. Furthermore, we calibrated the preamplifier using three different test pulses for two different shape times. Unfortunately the study of radioactive sources was not possible with our semiconductor detector since we measured too much background noise.

6 Exercise 3

Finally, we compared the *IV* curve of the non-irridiated, n-doped bulk semiconductor sample that we studied in the clean room with a corresponding Gss simulation. For the simulation, a thickness of 300 μm and a width of 5000 μm was chosen. The acceptor concentration was set to $5 \cdot 10^{18}$ cm^{-3} with a depth of 2 μm. The bulk concentration on the other hand was given by $1 \cdot 10^{12}$ cm^{-3}.

The simulated and measured *IV* curves are illustrated together in Figure 7. Obviously, the graphs show a significant discrepancy in their saturation current and their estimated depletion voltage.

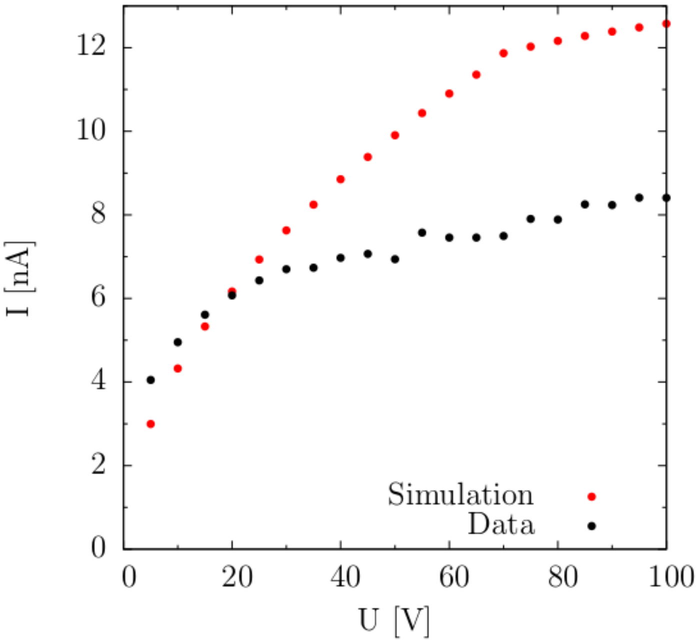


Figure 7: The simulated and measuerd *IV* curve for a non-irridiated, n-doped bulk semiconductor.

The depletion voltage depends on teh resistivity of teh material which may be different between measured device and simulated.
One would expect that leakage current is better in simulation since it has no additional sources as experimental data may have. Perhaps a small difference in temperature could explain the difference.