Laboratory exercise on semiconductor detectors, parts 2 and 3

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Setup

The diode was prepared for connection to the Vero board by soldering. We then connected the diode to the Vero board which provided easy connection possibilities to the preamplifier and an oscilloscope for calibration and noise measurements.

Pre-amplifier noise measurements

Before any measurements were conducted, the properties of the pre-amplifier[1] were determined experimentally. Initially, the injected charge Q was established by

$$Q = C_{calib} V_{in}, \tag{1}$$

where C_{calib} is the calibration capacitance (0.4 pF) and V_{in} the input voltage. The output voltage V_{out} was read out by an oscilloscope and varied as different load capacitors C_{load} were used in the circuit. In table 1 the charge calculated by eq. (1) is presented for various load capacitors. The charge was expected to remain constant, but was found to vary slightly. Taking the average as our estimate, the charge injected through the test capacitor was 9.6 fC.

Furthermore, the equivalent noise charge (ENC) as a measure of how much charge needs to be deposited in the detector in order to achieve a signal to noise ratio of 1, was calculated. The root-mean-square noise voltage (V_{rms}) was measured at the pre-amplifier output and converted to the noise voltage input by division by the gain G of the pre-amplifier. The gain was defined as the ratio between the output voltage V_{out} and the input voltage V_{in}. These values are also summarized in Tab. 1 whereby the noise measurements were conducted while not feeding a pulse into the per-amplifier. Hence, the ENC can be found as:

$$Q_{ENC} = \frac{V_{rms}}{G} C_{\text{load}}. \tag{2}$$

= V(rms)/V(out) * Q(in)

The measured ENC of the investigated pre-amplifier was fitted linearly and is presented in Fig. 2. The established fit parameters were an offset of −356(76) e and a slope of 1111(40) e/pF. However, the two measurements with 54 pF and 100 pF where found to be not match this linear prediction.

Further values of Tab. 1 are visualized in Fig. 1 where V_{out}, rising time and noise V_{rms} are plotted as a functions of C_{load}. The V_{out} seems to be inversely proportional to the capacitance of the load capacitor (following $C = Q/V$). The rising time does not show any dependence on load capacitor. The noise increases with increasing load capacitance.

[1] Similar to A1422H by CAEN http://www.caen.it/csite/CaenProd.jsp?parent=13&idmod=774

Table 1: Responses of the pre-amplifier to input pulses under various load capacitors C_{load}. Pulses of amplitude V_{in} where applied to through the calibration capacitor to measure the deposited charge Q. Noise measurements were conducted without injecting calibration pulses.

C_{load} [pF]	V_{in}[mV]	V_{out} [mV]	rise time [ns]	V_{rms} [µV]	Q [fC]
0	22.45 ± 1.32	66.64 ± 0.74	26.49 ± 3.65	379.81 ± 25.29	9.0
1	22.98 ± 1.43	66.47 ± 0.68	27.12 ± 4.42	380.01 ± 26.64	9.2
4.7	22.9 ± 1.14	63.49 ± 0.83	28.04 ± 4.78	356.13 ± 22.56	9.2
10	23.66 ± 1.21	59.62 ± 0.63	26.07 ± 1.71	397.69 ± 25.61	9.5
27	25.21 ± 0.23	50.99 ± 0.70	25.35 ± 9.16	400.70 ± 24.69	10.1
54	25.2 ± 0.20	41.20 ± 0.40	25.90 ± 0.99	509.13 ± 45.96	10.1
100	25.28 ± 0.34	32.37 ± 0.82	25.37 ± 6.06	579.55 ± 41.37	10.1

Why did test signal change amplitude?

Unexpected, should get slover with capacitance...

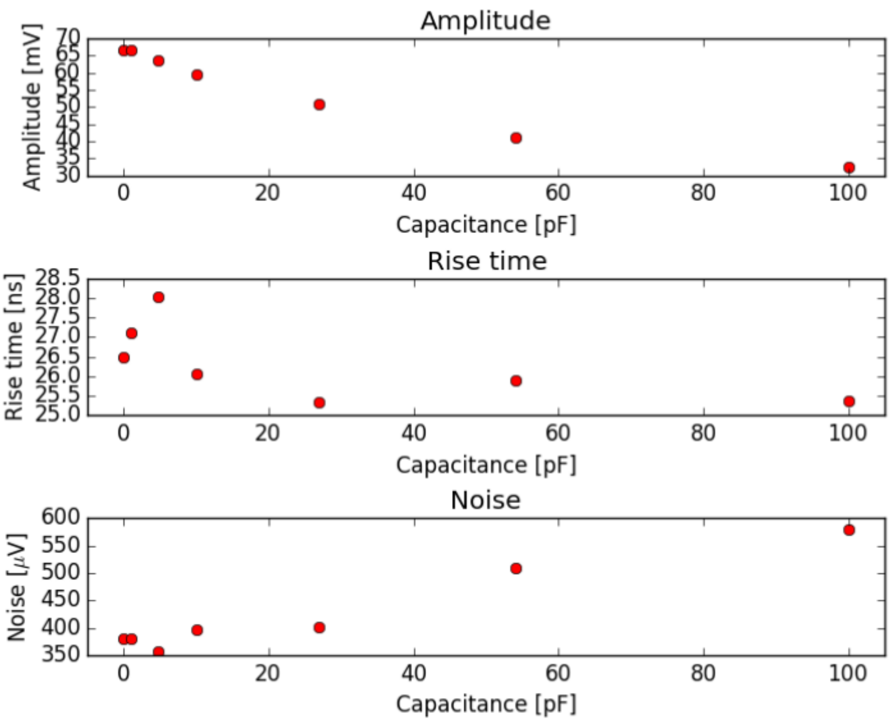


Figure 1: Illustration of pre-amplifier properties.

Spectroscopy amplifier calibration and ^{137}Cs spectrum

In order to study the pre-amplifier performance we used a spectroscopy smplifier (SA) and a pulse height analyzer (PHA). We performed a three point gain calibration with 10 mV, 20 mV and 30 mV test pulses for two shaping times of the SA. The test pulses correspond to 1, 2, 3 minimum ionizing particles (MIP) respectively. The shaping time of amplifiers describes the amount of time the capacitor has to collect the charge.

The spectra can be found in figure 3. The calibration in plot 3a failed for reasons that are not clear. Unexpectedly, there are five peaks in the spectrum for the long shaping time of 16 μs. This could be explained with lower voltage injected pulses which were supposed to be used only for testing and were recorded into the data file. An other explanation might be noise. Also, the injected signals are shifted to higher channel numbers than expected. The comparison of the two calibrations shows that the peaks for a longer shaping time are shifted to higher voltages. Due to these issues, only the calibration corresponding to the 2 µs shaping time was used in the following. This configuration yielded a linear relation between voltage V and channel number c given by

X The two peaks at low energy are from overshoot from falling edge of the testpulse.

$$V = 2.86\,\frac{\mathrm{kV}}{\mathrm{ch}}c + 3.92\,\mathrm{kV} \tag{3}$$

Unfortunately, we did not have enough time to measure the ENC noise for the two shaping times and a comparison with the measurement with the oscilloscope.

Instead, we took measurements using a ^{137}Cs source, using a shaping time of 2 µs. That data is shown in Fig. 4, after noise subtraction and calibration. Two peaks of different intensity are visible in the spectrum.

Simulation for comparison to clean room measurements

Conclusively, the GSS simulation software was used to simulate an IV curve for a diode similar to the one measured in the clean room. The result from the clean room measurement is depicted in Fig. 5, while the result of the simulation is shown in Fig. 6. While the shapes show a remote resemblance to each other, it was not possible to reproduce the order of magnitude of the leakage current (nA) nor the full depletion voltage ($V_{fd} = 25.16 \pm 0.20$V) observed in the clean room.

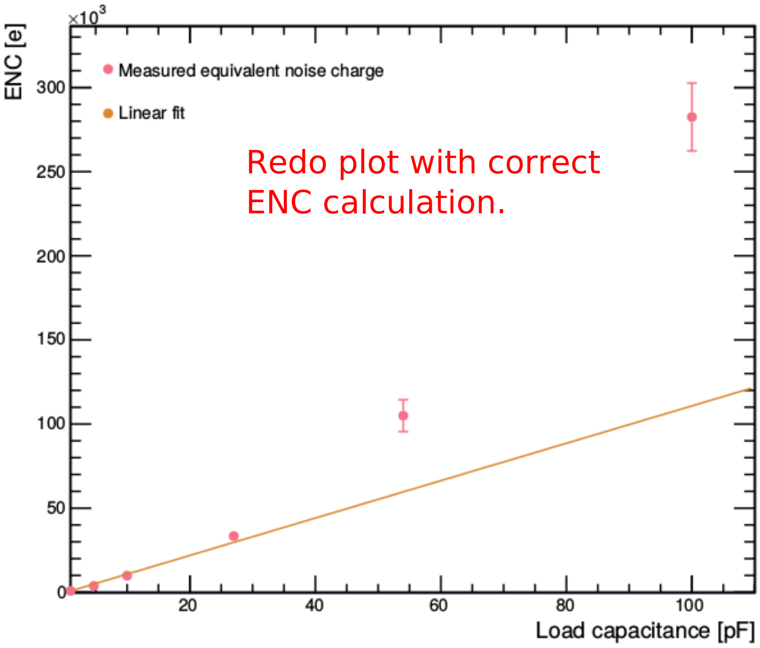
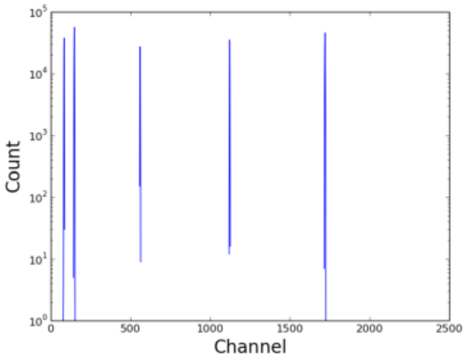


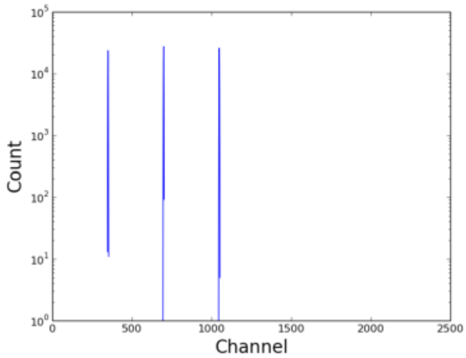
Figure 2: Equivalent noise charge for various load capacitors. The linear fit yielded an offset of −356(76) e and a slope of 1111(40) e/pF

Conclusion

The two parts of this semiconductor laboratory exercise focused on the study of amplifier noise measurements, calibrations and a simple measurement of a ^{137}Cs source sample. Due to time constrains some of the measurements had to be skipped or sub-optimal data had to be used "as is".



(a) The calibration spectrum for a shaping time of 16 μs.



(b) Calibration spectrum for a shaping time of 2 μ.

Figure 3: Calibration spectra for two different shaping times with injected test pulses of 10 mV, 20 mV and 30 mV. The channel number corresponds to voltage and the peaks to the injected signal.

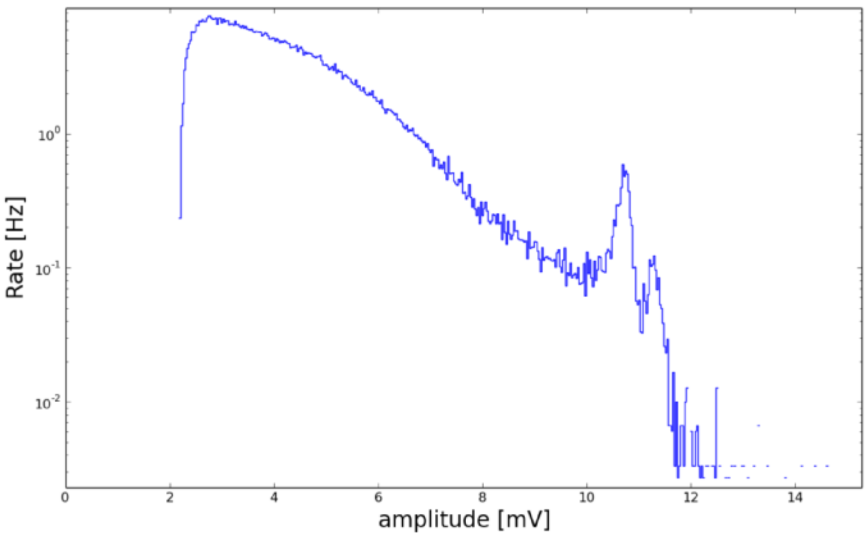


Figure 4: The ^{137}Cs using the using the 2 µs shaping time calibration.

To see nice spectrum with Am source please have a look in A. Burgmans report.

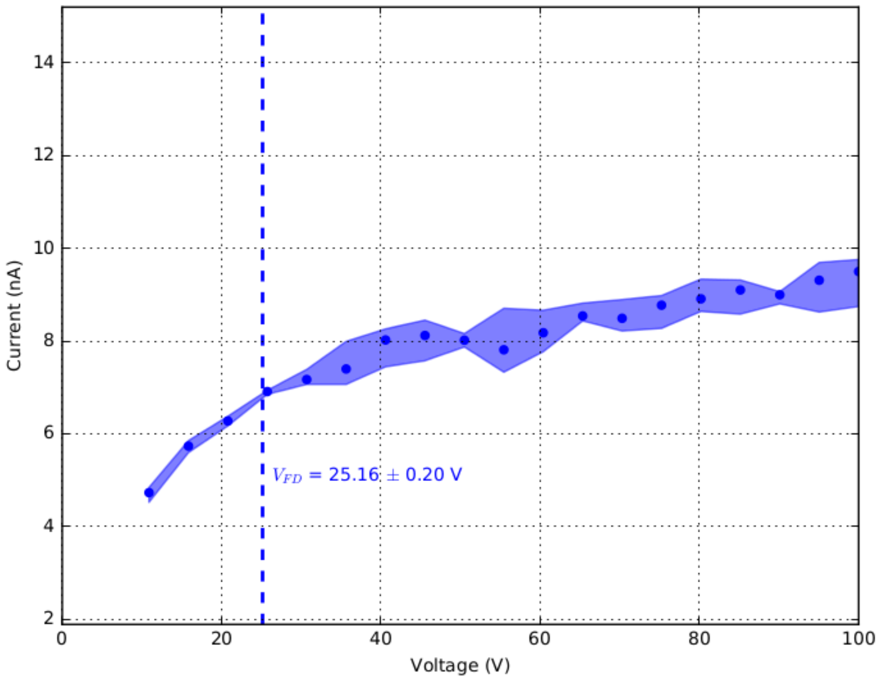


Figure 5: IV curves obtained from the clean room measurements. "Sample 18" represents the diode which was simulated in this exercise.

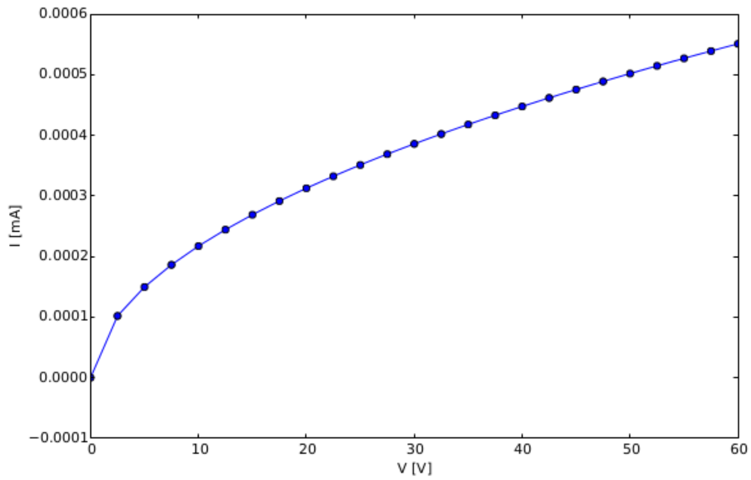


Figure 6: Simulated IV curve for "Sample 18" (cf. Fig. 5) from the clean room measurements. Neither the absolute value of the leakage current nor the full depletion voltage could be reproduced in the simulation.

The depletion voltage depends on resistivity which may be defferent between simulated and measured.
The leakage however is a mystery since one would expect that simulation is optimal and lower for an identical geometry.