Shaper Measurements

First measurements of shapers are done using standardized ESD target mounted on $1\text{m}\times1\text{m}$ aluminum plate. Three shapers are measured, namely shaper #1, shaper #7a (with sharp edges) and shaper #7b (with round edges). The photos are shown in Figs. 1, 2 and 3, respectively.

The measurement system consists of a shaper that is excited with DC voltage $E_3 = 10\,\text{V}$ connected in series with $R = 100\,\text{M}\Omega$. The shaper output is connected to high-voltage reed relay. High-voltage reed relay is turned on by low-voltage relay that connects DC power supply $E_2 = 25\,\text{V}$ to control pints of high-voltage reed relay. Low-voltage relay has DC power supply $E_1 = 5\,\text{V}$ and is controlled by a train of pulses $V_{\text{on}} = 5\,\text{V}$, $V_{\text{off}} = 0$, frequency 0.1 Hz and 50% duty cycle. The photo of the measurement system is shown in Fig. 4.

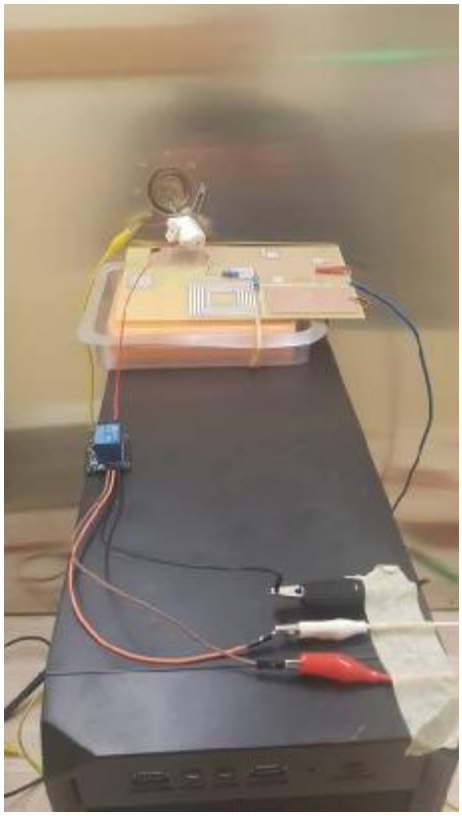

Figure 1. Shaper #1.

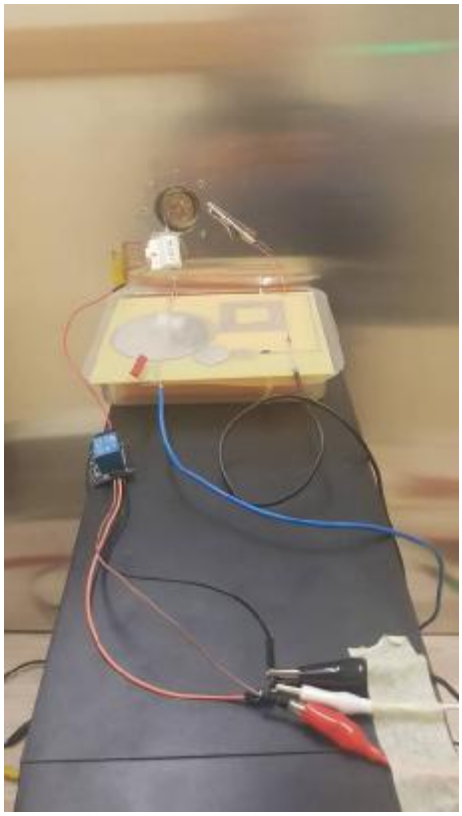

Figure 2. Shaper #7a (sharp edges).

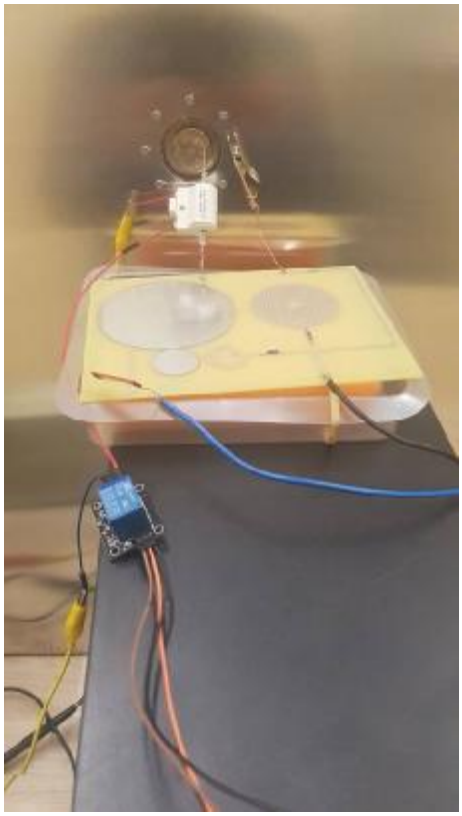

Figure 3. Shaper #7b (round edges).

Measurements for each shaper are repeated for 10 times. The results are shown in Figs. 7, 8 and 9. The results show that by using the described measurement system measurements are repeatable. The response for shaper #1 is closest to IEC 61000-4-2 standard, while results for shaper #7a and #7b shown larger peak current than expected.

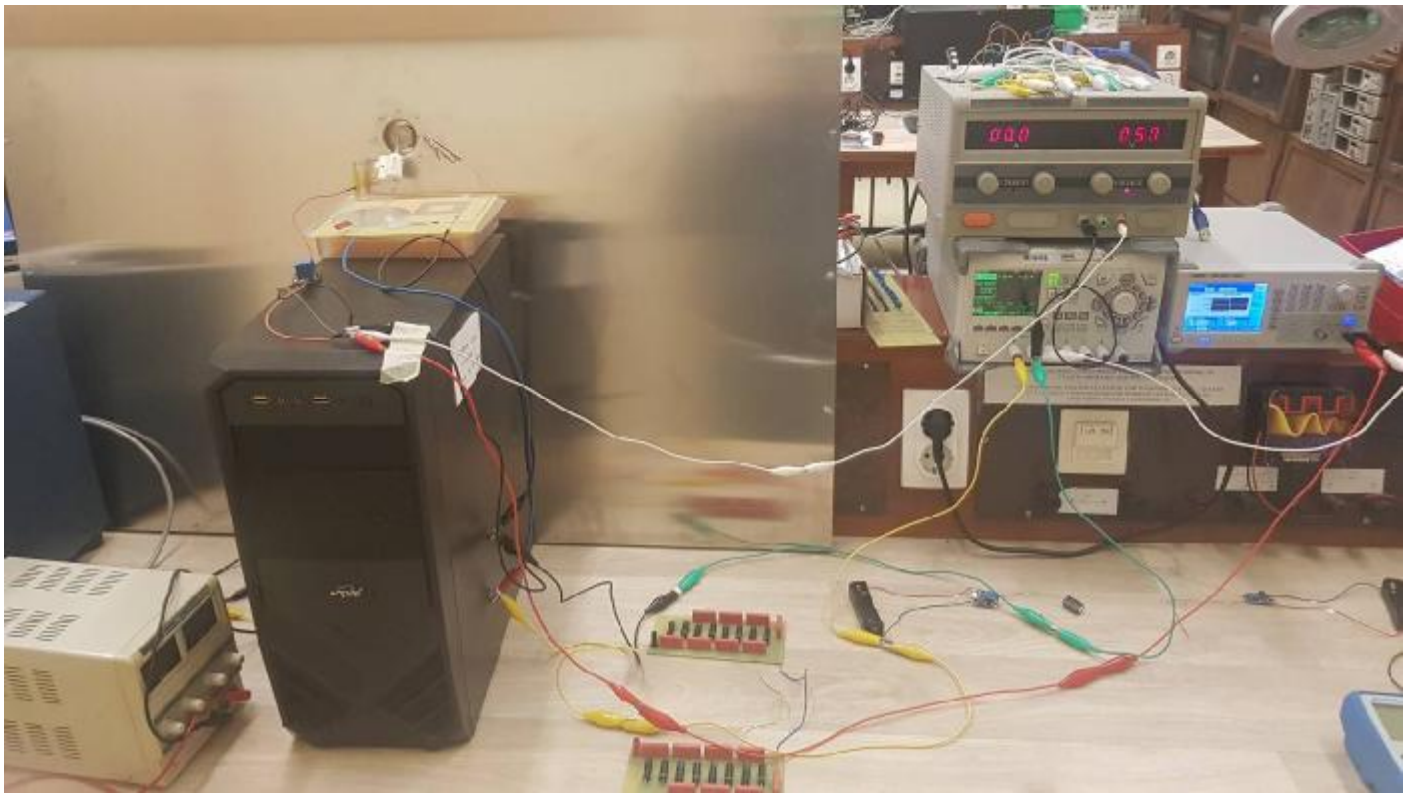

Figure 4. Measurement system for shaper response.

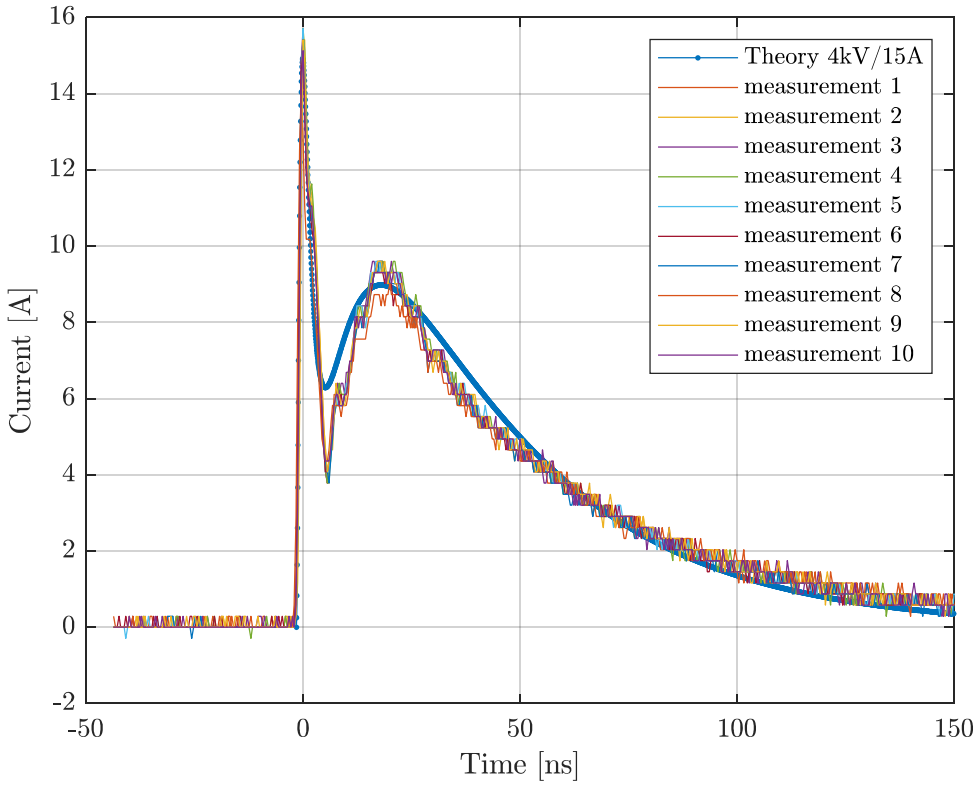

Figure 5. Measured results for shaper #1.

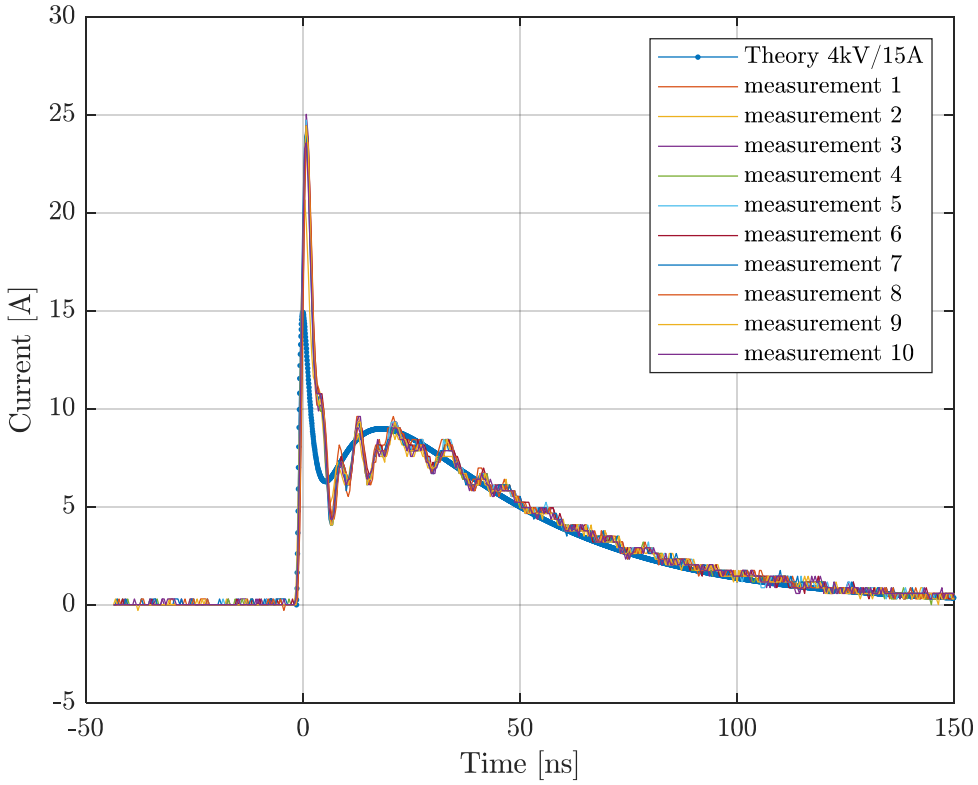

Figure 6. Measured results for shaper #7a (sharp edges).

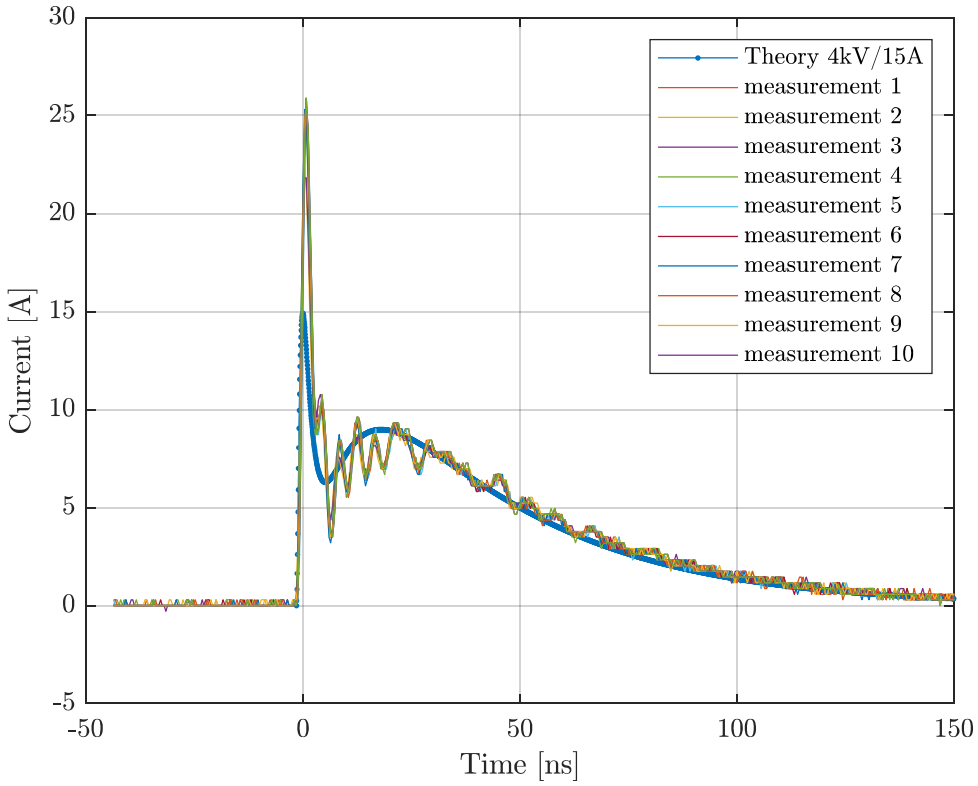

Figure 7. Measured results for shaper #7b (round edges).

Shaper Testing at High Voltages

High voltage is applied to all three shapers. The photos are shown in Figs. 8, 9 and 10, respectively. None of the shapers can withstand 15 kV due to the breakdowns so the next versions of shapers are designed and are being prototyped.

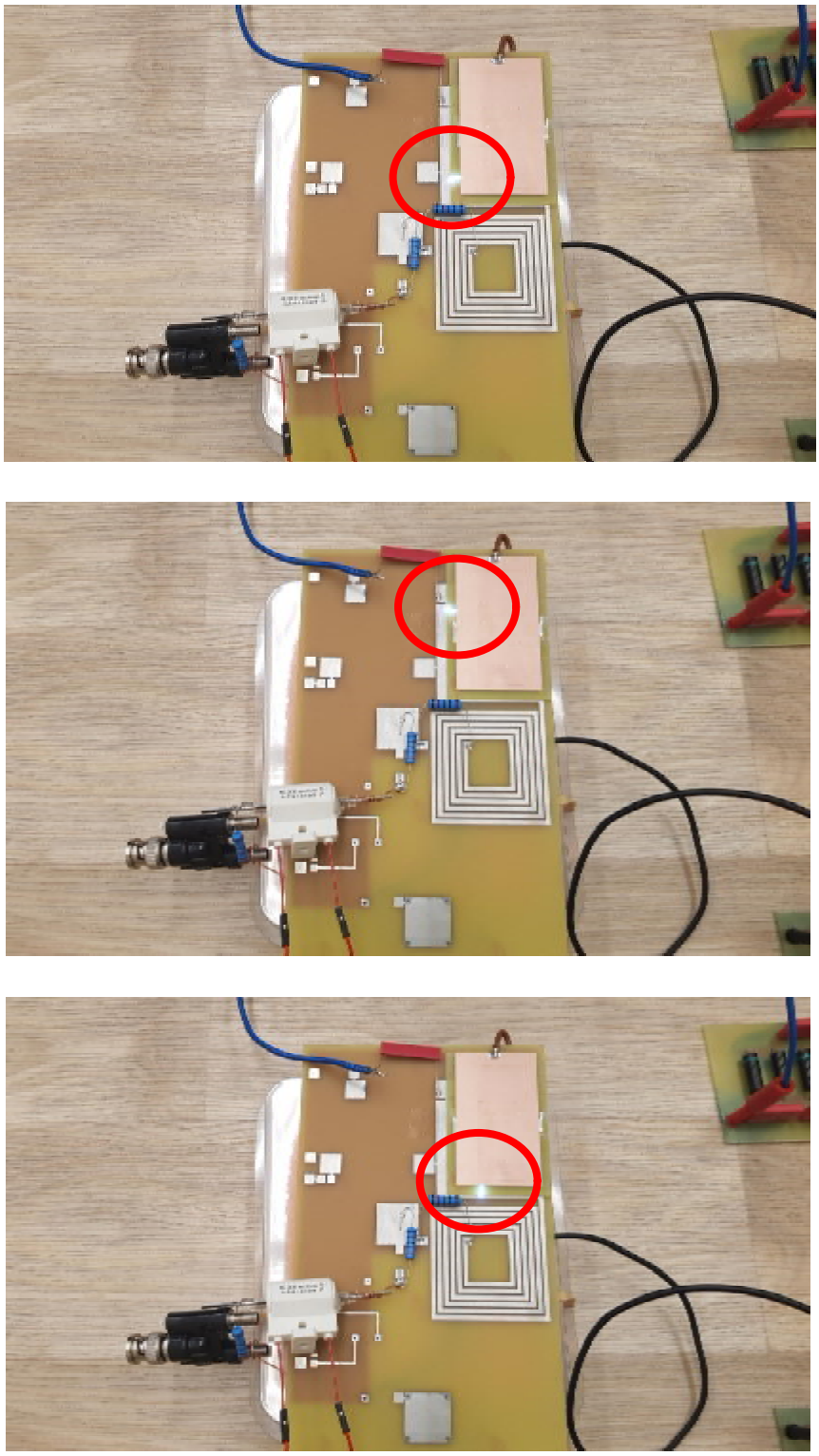

Figure 8. Breakdowns for shaper #1 at high voltage.

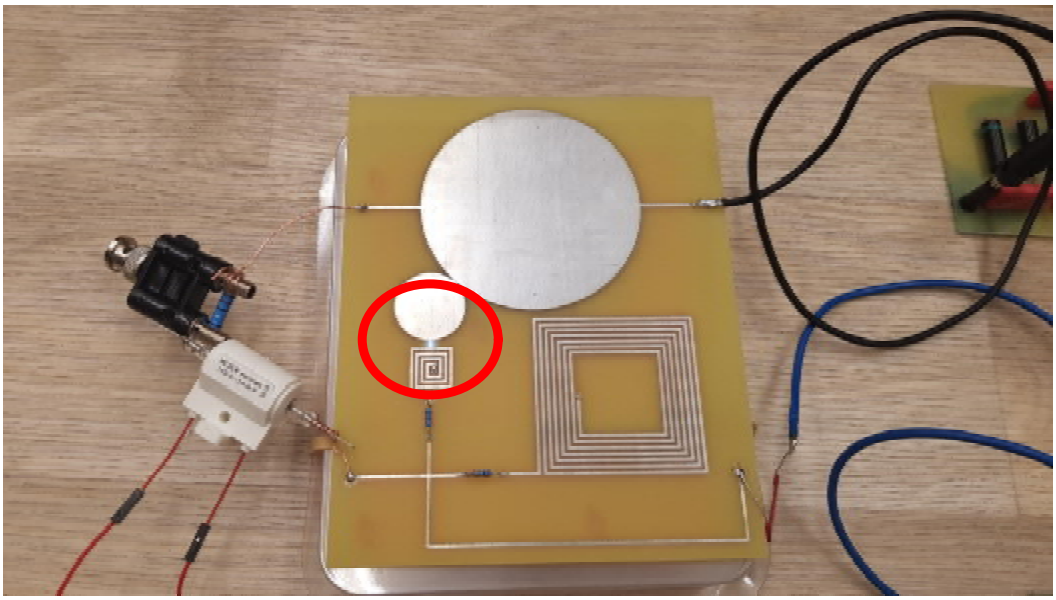

Figure 9. Breakdown for shaper #7a at high voltage.

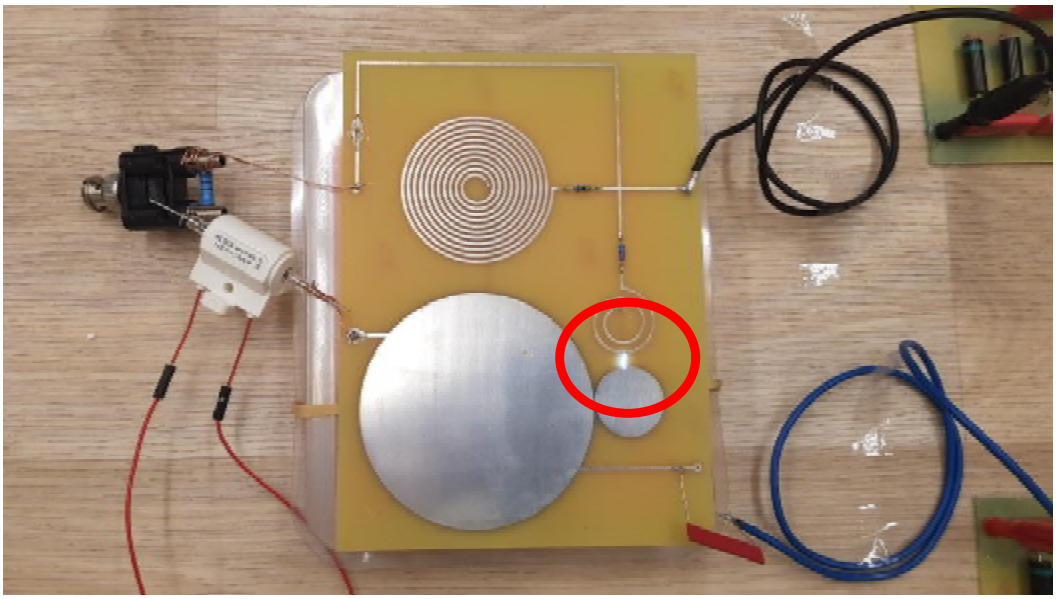

Figure 10. Breakdown for shaper #7b at high voltage.

ESD Target Calibration

According to the IEC 61000-4-2 standard the standardized ESD target should be calibrated in the following manner. The current of a DC source is set to a known current (we used $I_{DC} = 100\,\text{mA}$). This source is connected to the target between the points where ESD generator should be tested. Then the voltage at oscilloscope, V_{osc}, should be measured. In our case the target is connected to the oscilloscope with a coaxial cable, without any additional attenuators and the input impedance of the oscilloscope is set to $Z_{osc} = 50\,\Omega$. Then the conversion factor between the measured voltage and excitation current is $Z = \frac{V_{osc}}{I_{DC}}$. We got $Z \approx 1.06\,\Omega$. The power supply DC voltage for the shaper measurements is set to 30 V, hence the conversion factor for this measurements (for comparison with 4 kV testing level) is $Z \cdot 4000/30$.

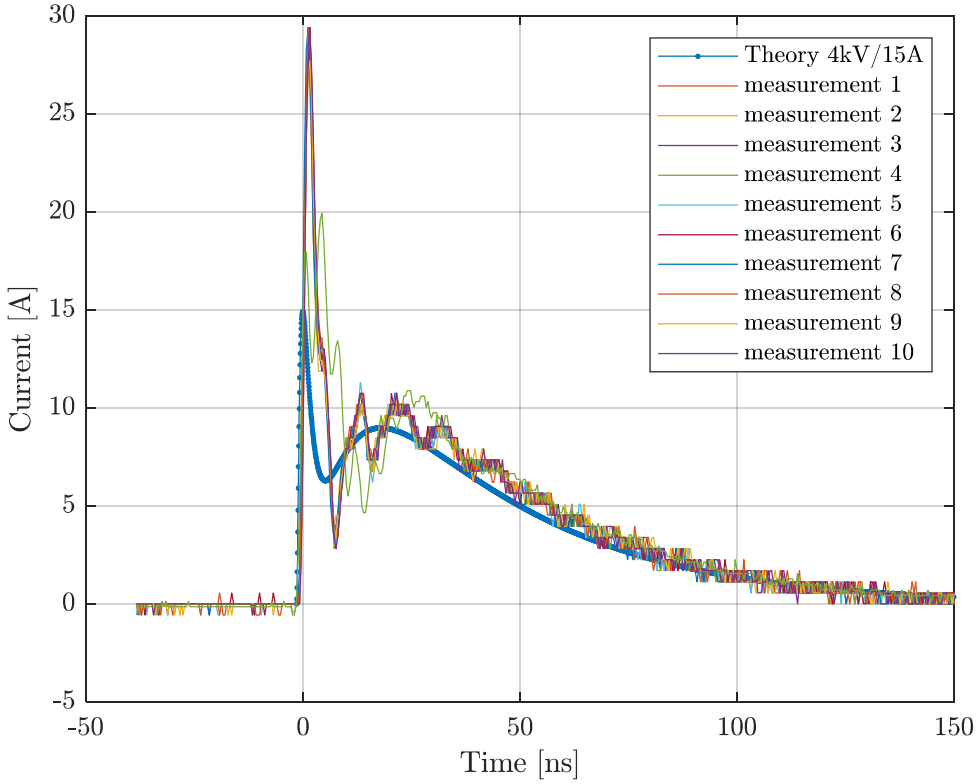

Figure 11. Calibrated measurement of shaper #7a (sharp-edge).

From the results in Fig. 11 it is observed that the peak of the initial pulse is almost two times larger than in the standard. In order to decrease that peak additional 650 nH inductor is connected in series with the non-grounded output of the shaper. The results are shown in Fig. 12. It can be seen that the response is better and that the initial peak is lowered, however the shaper of the first pulse is distorted.

Additional measurements for shaper #7a have shown that the printed elements are within the expected production tolerances. However, the peak of the first pulse is heavily affected by the parasitic capacitances between inductors and capacitors, and to some level to the parasitic inductances of printed lines.

Finally, the calibrated measurements for shaper #1 are done. The results are shown in Fig. 13. While the shaper #1 has 18 A peak current instead of 15 A it is still the closest to the theoretical of all tested shapers.

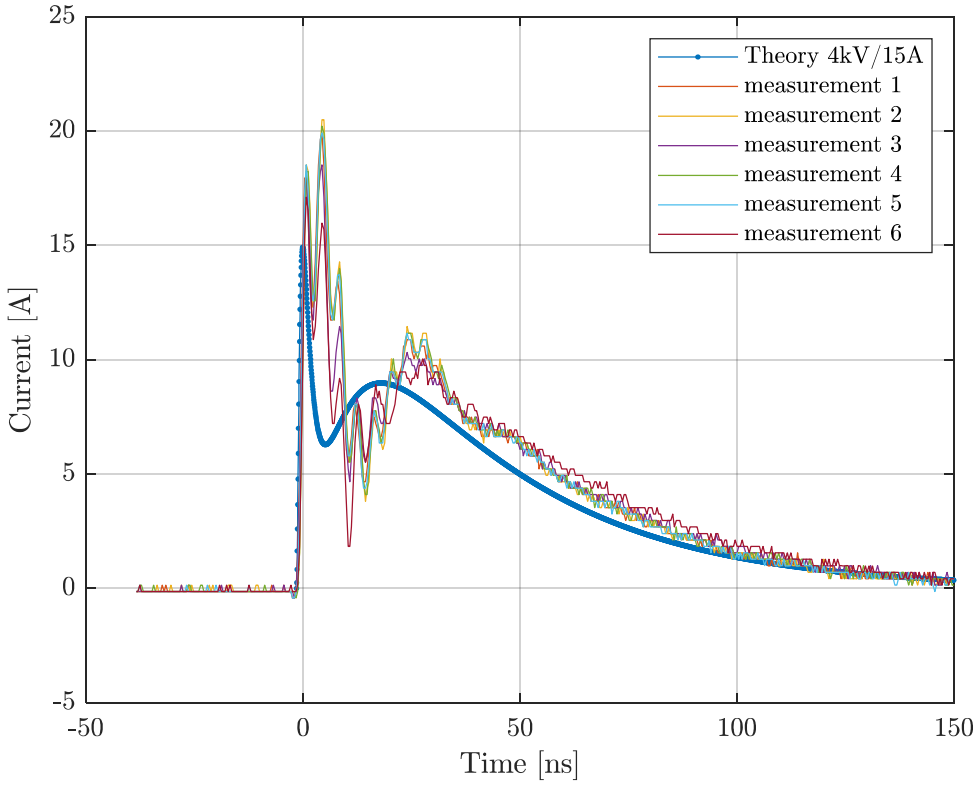

Figure 12. Calibrated measurements of shaper #7a with additional 650 nH inductor in series.

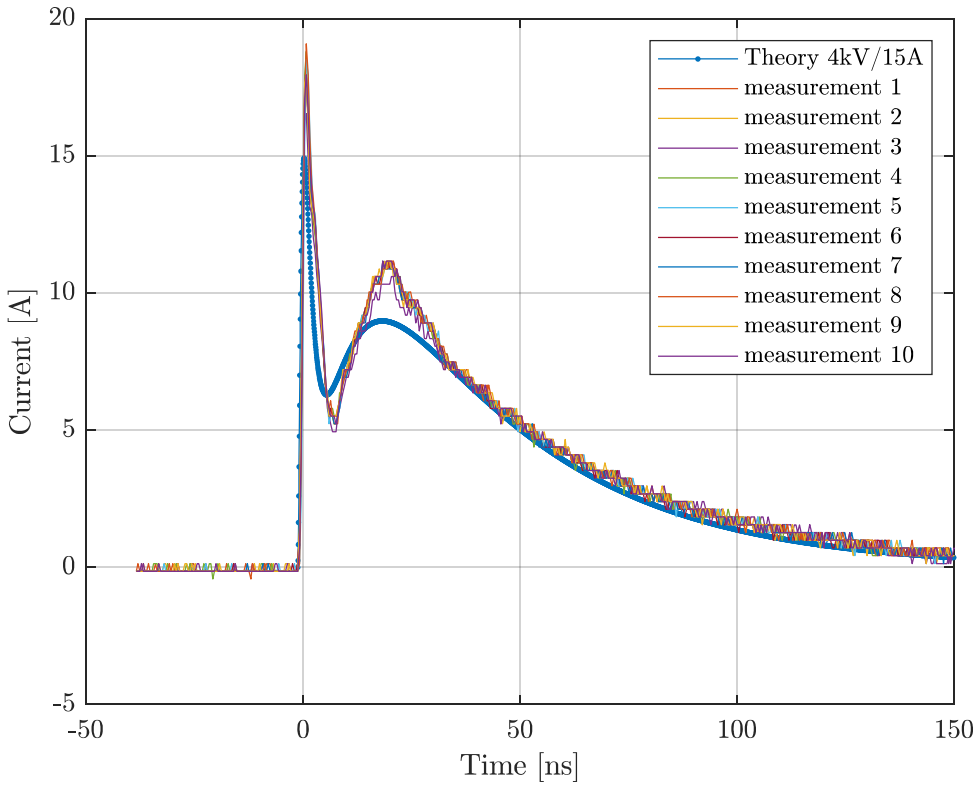

Figure 13. Calibrated measurement of shaper #1.

Revision history

Version	Date	Author(s)	Description
1.0	21/01/2025	D.O., A.K., A.Dj.	Created