Measurement Report:

TLP-3010C VF-TLP Waveforms

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Contents

1 Introduction

1.1 Scope

This report compares vf-TLP measurements of two different probe setups using the HPPI TLP-3010C:

High Performance Probes: Kelvin measurement with 40 GHz Cascade ACP-40 probes

Low Cost Probes: Kelvin measurement with 7 GHz Picoprobe Model-10 probes

Three different setups are investigated:

1. Kelvin measurement with 40 GHz Cascade ACP-40 probes
2. Kelvin measurement with 7 GHz Picoprobe Model-10 probes
3. 1-port TDR-S measurement with Cascade ACP40

1.2 Calibration Substrate

A calibration substrate from Cascade is used to verify the quality when measuring a short circuit, an open circuit and a 50 Ω load.

1.3 12 GHz, 40 GS/s Sampling Oscilloscope

All measurements in this report were performed with a Tektronix TDS6124C or an Agilent Infiniium DSO81204A, both with 12 GHz bandwidth and 40 GS/s sample rate.

1.4 Acknowledgement

The Kelvin measurements with Cascade ACP-40 probes were performed at the University of the federal armed forces, Neubiberg, Germany.

2 Kelvin measurement with 40 GHz Cascade ACP-40 probes

This is the best method available for vf-TLP measurements, but also the most inflexible. RF-probes have a fixed pitch and changing to a new pair is tedious. Also, the device pads must be large enough to accommodate both probe tips (see Fig. 2). One of the probes is ordered with an integrated series resistor which enables voltage sense with minimal load of the measured circuit. The small current flowing through the sense probe is subtracted from the current measurement in the HPPI TLP control software. The bandwidth of the sense probe is specified to 10 GHz by Cascade.

A pair of probes cost about 2000 EURO.

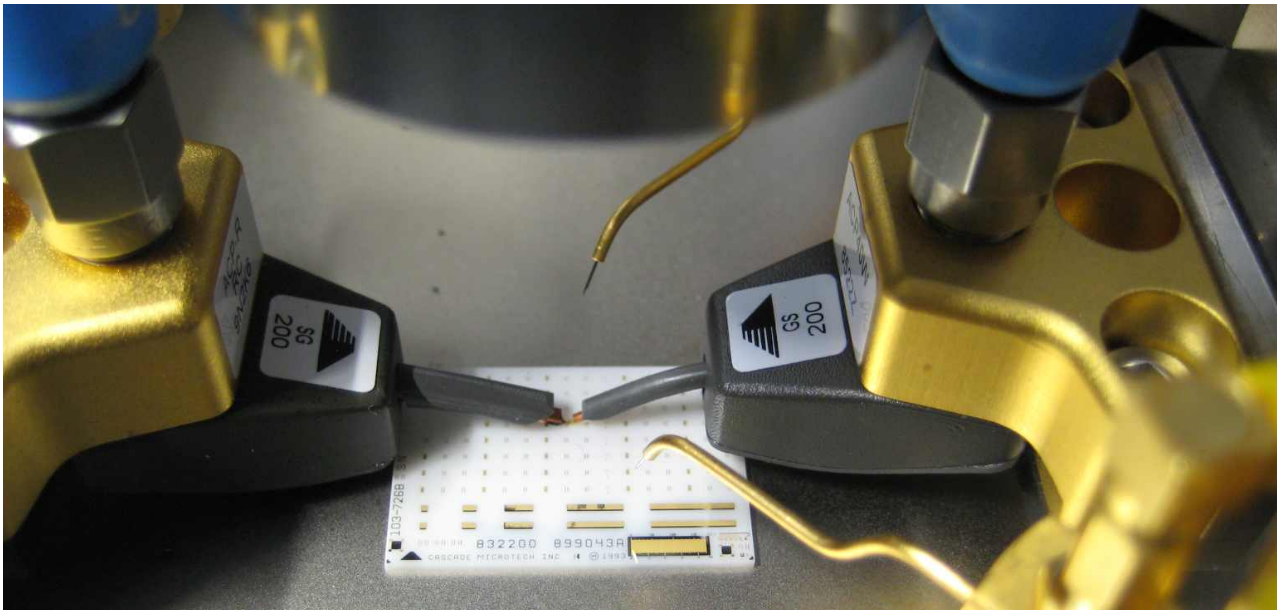


Figure 1: Kelvin setup with Cascade ACP-40 probes. The left probe has an integrated 1k resistor for direct voltage sense at the device pads.

2.1 Short Circuit

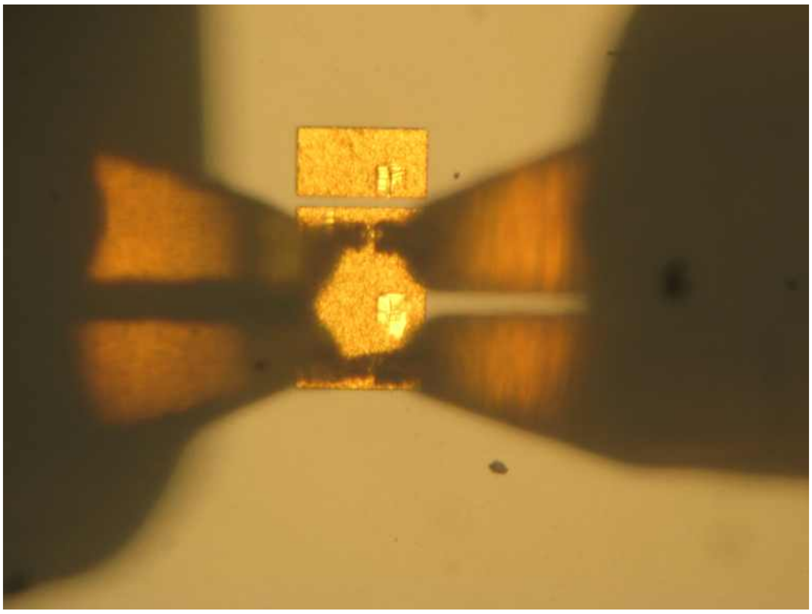


Figure 2: Microscope image of ACP-40 probe tips contacting a short circuit consisting of a massive copper area on the calibration substrate. The probe pitch is 200 μm.

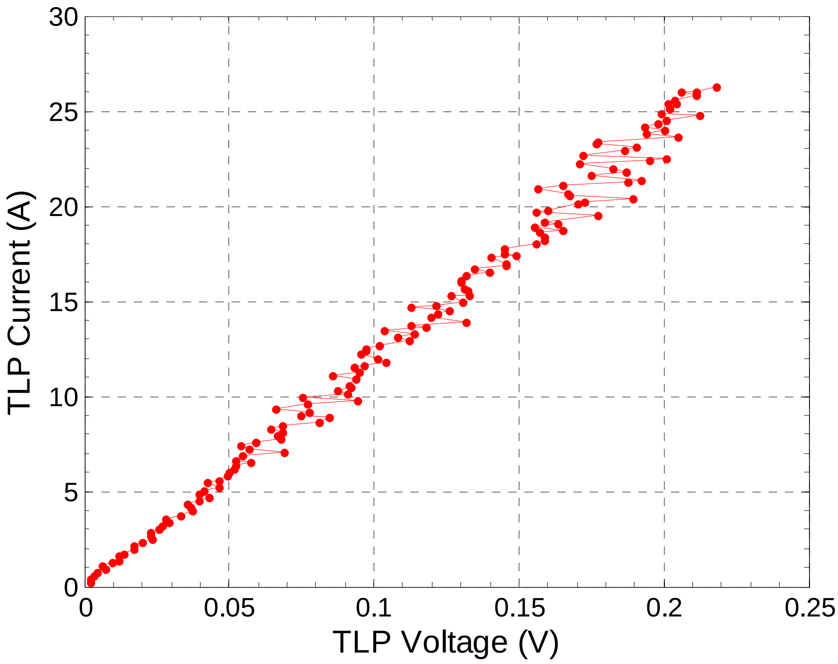


Figure 3: I-V curve measured over a short with a 2.5 ns wide pulse with 100 ps rise time. The data is averaged from 1 to 2.2 ns. The low series resistance of approx. 8 mΩ shows the advantage of the Kelvin method.

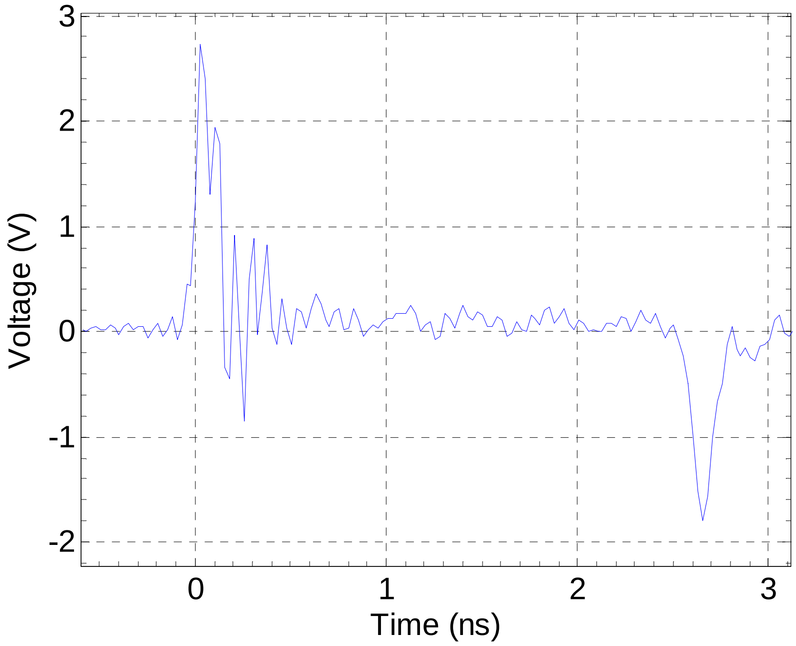


Figure 4: Measured Transient voltage during a 2.5 ns, 100 ps rise time, 10 A pulse into a short (Fig. 2). The overshoot is caused by the inductance of the short circuit plus inductive coupling between the force and sense probes.

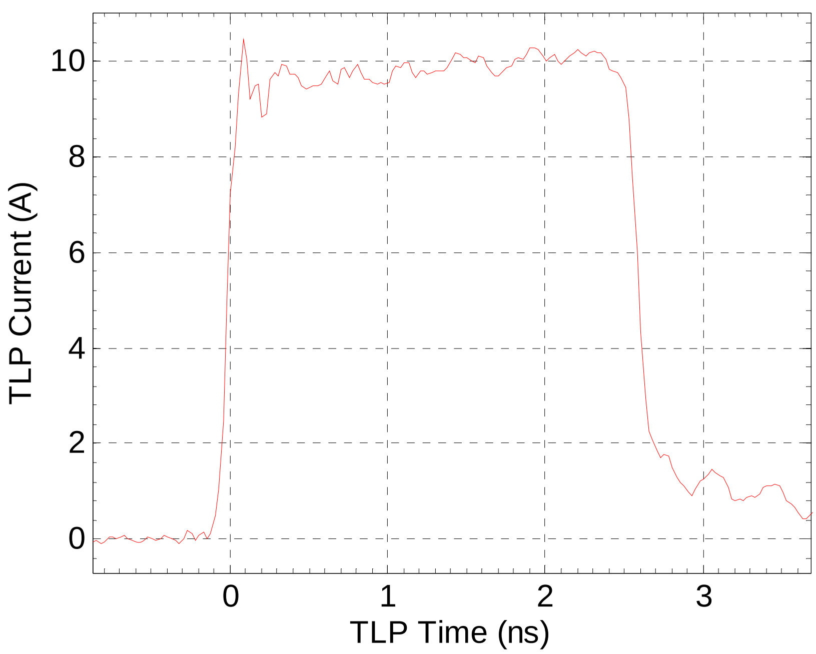


Figure 5: Measured transient current during a 2.5 ns, 100 ps rise time, 10 A pulse into a short (Fig. 2).

2.2 Open Circuit

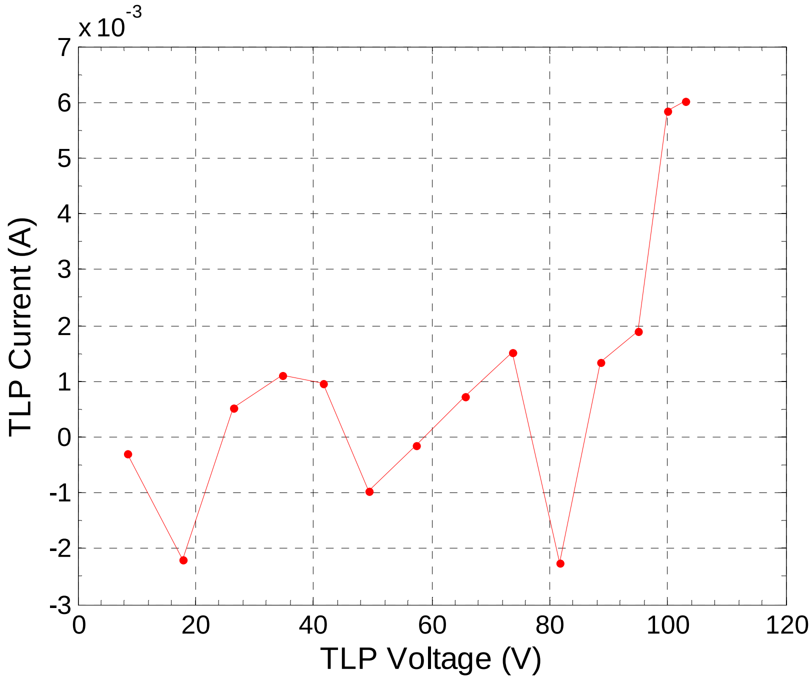


Figure 6: I-V curve measured over an open circuit with a 2.5 ns wide pulse with 100 ps rise time. The data is averaged from 1 to 2.2 ns. **Note: y-axis shows milliamperes**.

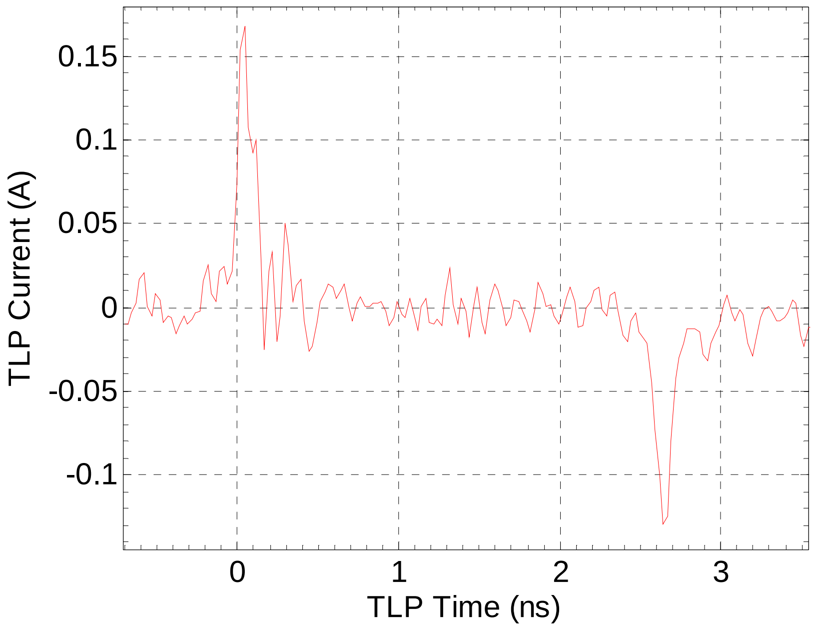


Figure 7: Measured transient current during a 2.5 ns, 100 ps rise time, 100 V pulse into an open circuit on a calibration substrate. A small capacitive current flows during the first 100 ps.

2.3 50 Ω Load

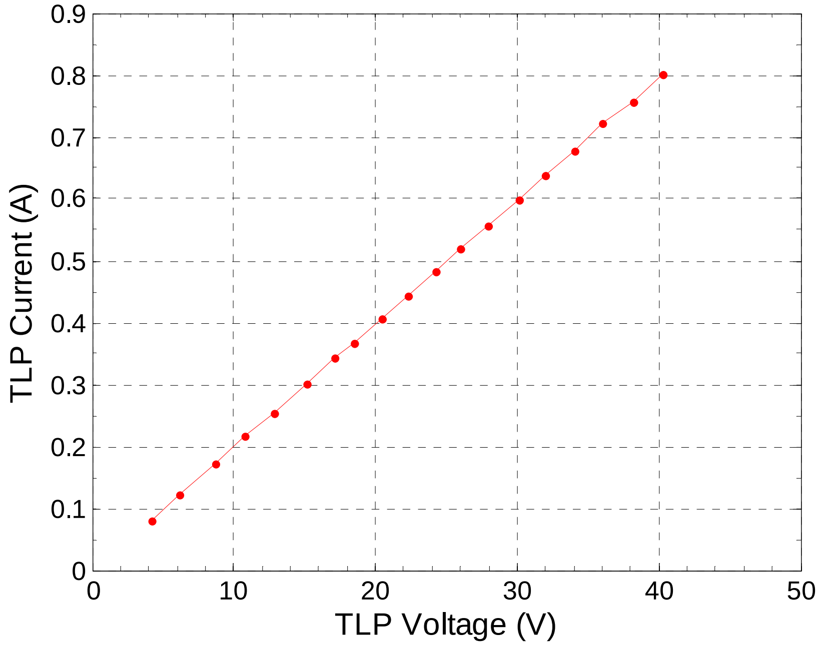
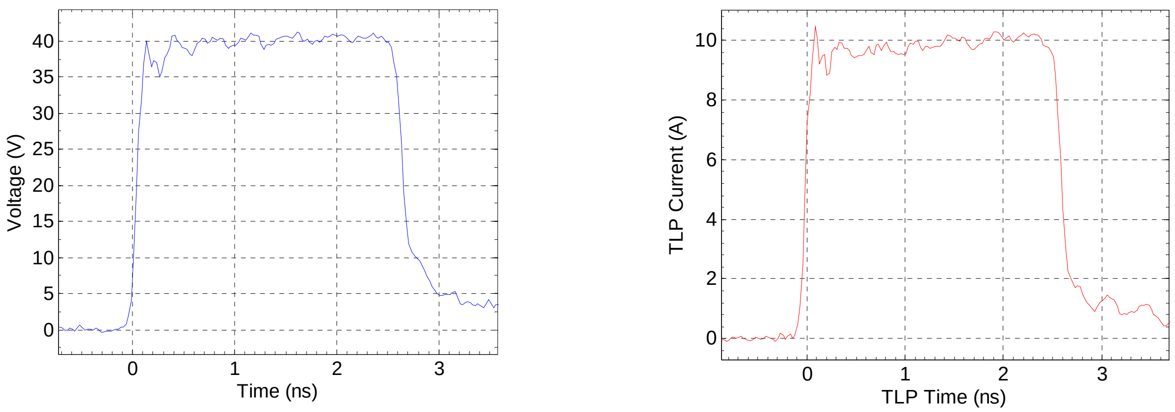


Figure 8: I-V curve measured over a 50 Ω load with a 2.5 ns wide pulse with 100 ps rise time. The data is averaged from 1 to 2.2 ns.



(a) Voltage waveform.

(b) Current waveform.

Figure 9: Voltage and current waveforms when measuring a 50 Ω load.

3 Kelvin Measurement with 7 GHz Picoprobe Model-10

Picoprobe model-10 is an RF-probe with exchangeable probe tips. The probe tip consists of a semi-rigid cable with two about 1 mm long probe needles at the end. It has not as high bandwidth as the 40 GHz Cascade ACP-40, but still enough for many measurements. A standard 50-Ohm probe is specified to 7 GHz. A sense probe with integrated resistor has 1-11 GHz depending on the chosen resistor value (5 GHz for 5 k, 11 GHz for 500 Ω). The power of this probing system is that the user can quickly change between probe tips of different pitch. Pitches up to 2 mm are available from GGB Industries. Spare probe tips cost about 40-60 EURO each.

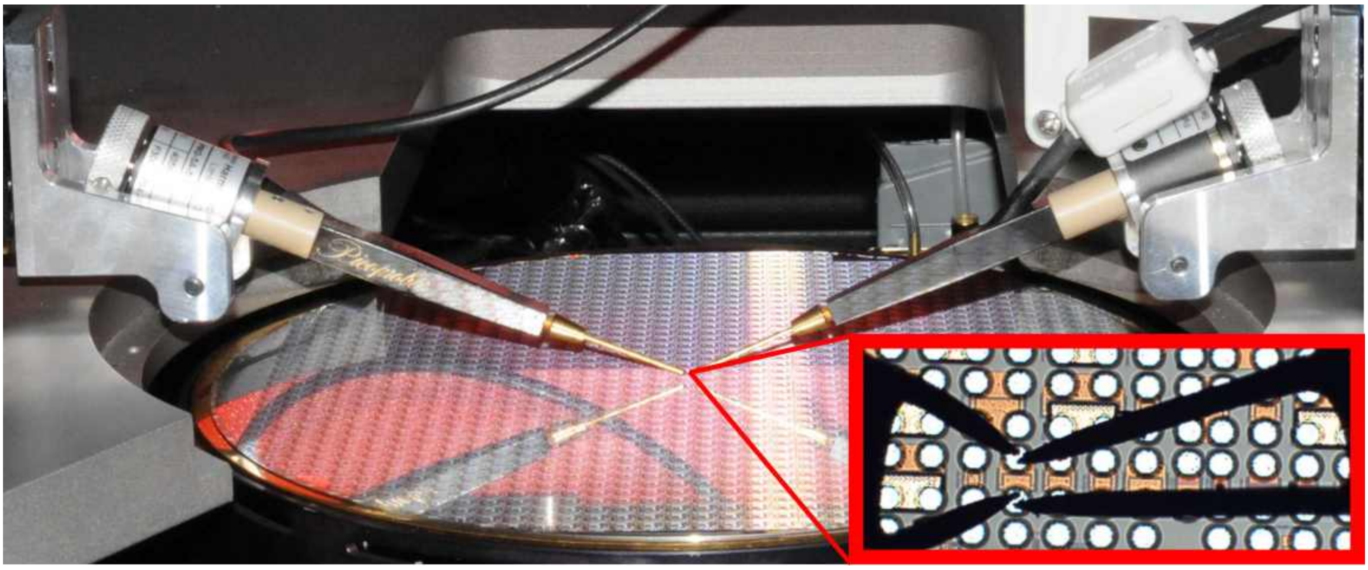


Figure 10: Kelvin setup with Picoprobe model-10. The right probe has an integrated 2.5 k resistor to sense the voltage with minimal load.

3.1 Short Circuit

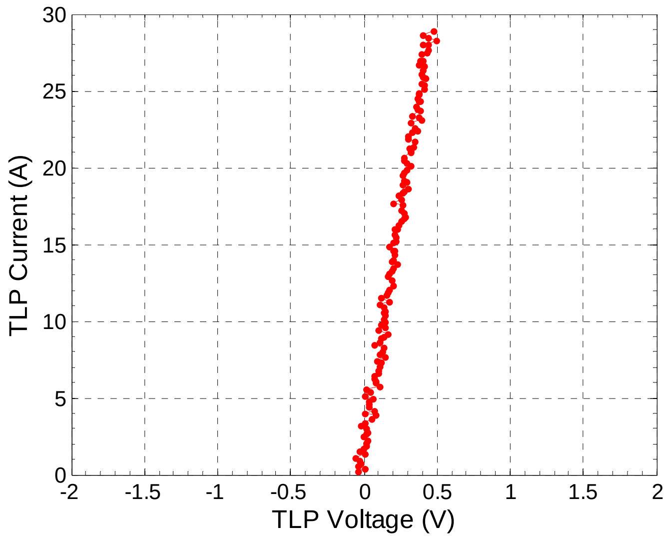


Figure 11: I-V curve measured over a short with a 2.5 ns wide pulse with 100 ps rise time. The data is averaged from 1 to 2.2 ns. Since the measurement is measured with a Kelvin setup there is no need of subtracting series resistance. The Ron of about 17 mΩ is rather the resistance of the metal itself.

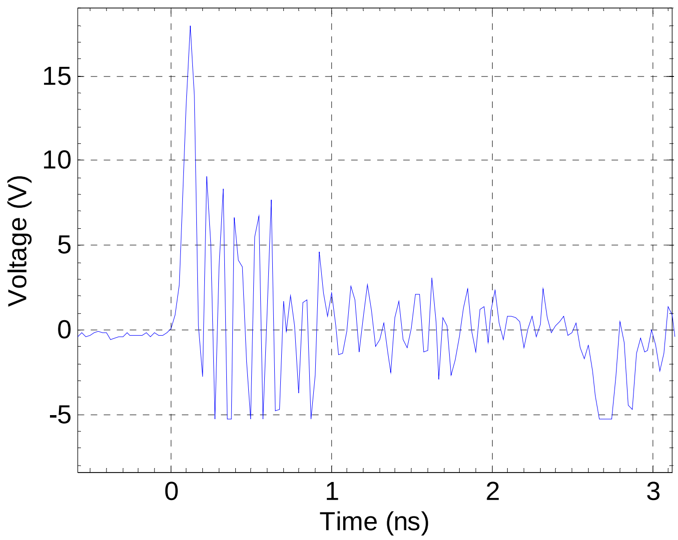


Figure 12: Transient voltage during a 2.5 ns, 100 ps rise time, 10 A pulse into a short. The ringing is caused by inductive coupling between the force and sense probes. **Note:** The scope bandwidth is 12 GHz and the noise is in the 10 GHz range. Since the bandwidth of the sense probe is limited to 5 GHz it would be favorable to apply a digital filter or use an analog low-pass filter.

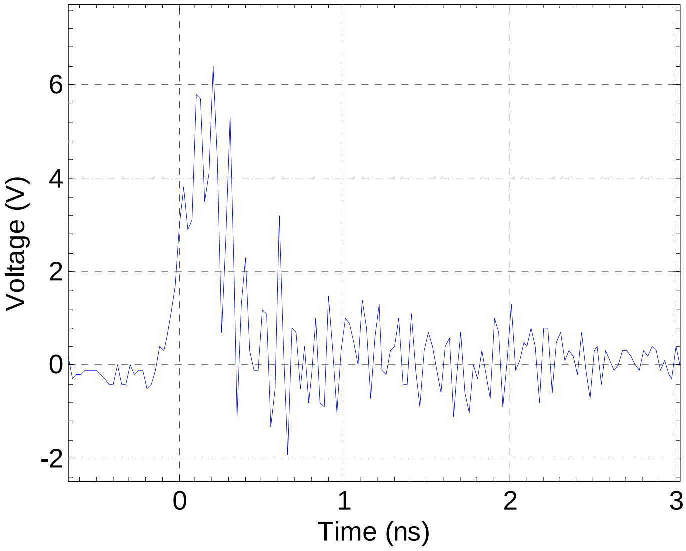


Figure 13: Transient voltage during a 5 ns, 300 ps rise time, 10 A pulse into a short. In comparison to fig. 12 the ringing is lower due to the slower pulse flank.

4 1-port TDR-S measurement with Cascade ACP40

This is the classical vf-TLP method introduced by Gieser et. Al. Both voltage and current is measured with a pickoff-Tee separated by a delay line of several meters to separate reflected from incident wave. The main problem with this method is that the voltage is derived by subtracting the reflected pulse from the incident one. Both incident and reflected waveforms are measured with an oscilloscope which has only limited vertical resolution, and is mostly rather inaccurate with respect to offset and ADC linearity. Thus, large noise and pulse to pulse instability appears.

The vertical resolution can be enhanced by averaging over several pulses. This has been done for the transient waveforms in fig. 16 and 17. However, averaging can hide a lot of device information e.g. pulse-to-pulse trigger instability. It also hides the transient signatures when a device fails, for example the point in time when a destructive second breakdown occurs.

In general, the noise from a TDR-S measurement is much larger than in a Picoprobe Kelvin setup. Thus, HPPI does not recommend this method except when absolutely necessary.

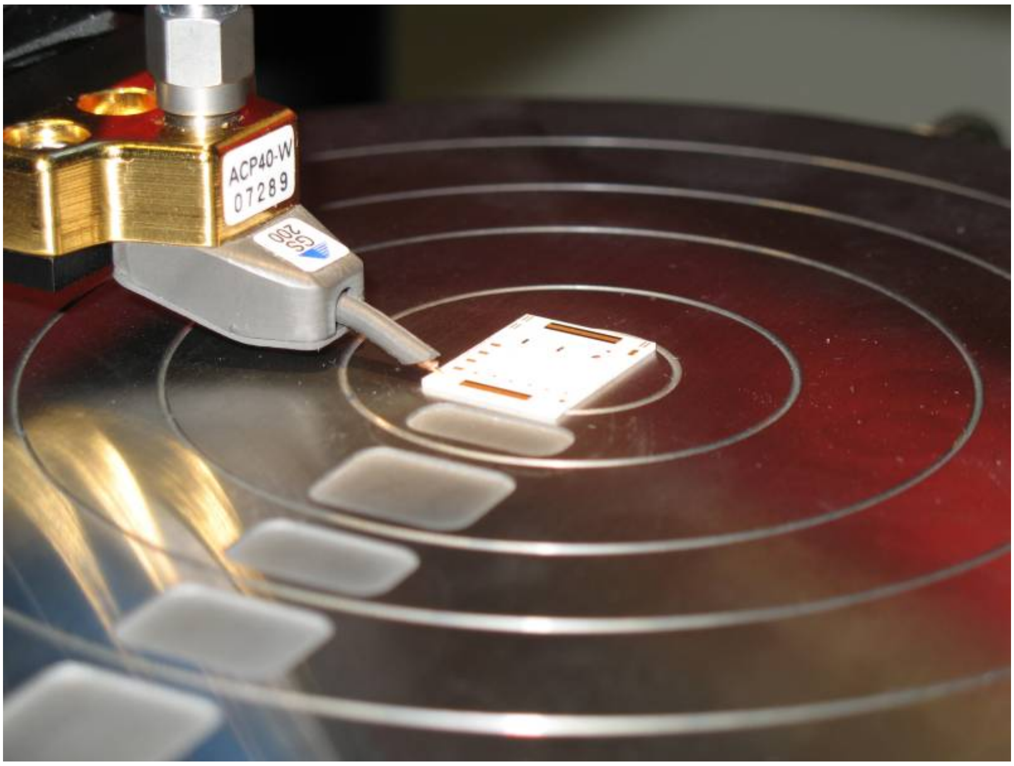


Figure 14: The measurement was performed on a calibration substrate. The inset figure shows a short circuit contacted with a probe with 200 μm pitch.

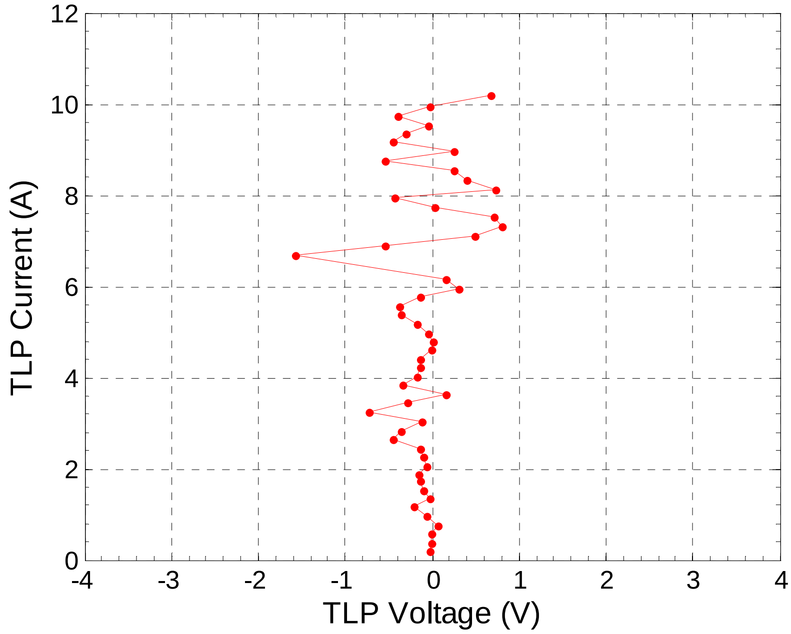


Figure 15: I-V curve measured over a short with a 2.5 ns wide pulse with 100 ps rise time. The data is averaged from 1 to 2.2 ns. The noise is related to the inaccuracy of the oscilloscope when two large amplitudes are subtracted. A parasitic contact resistance of 0.25 Ω has been subtracted from the voltage.

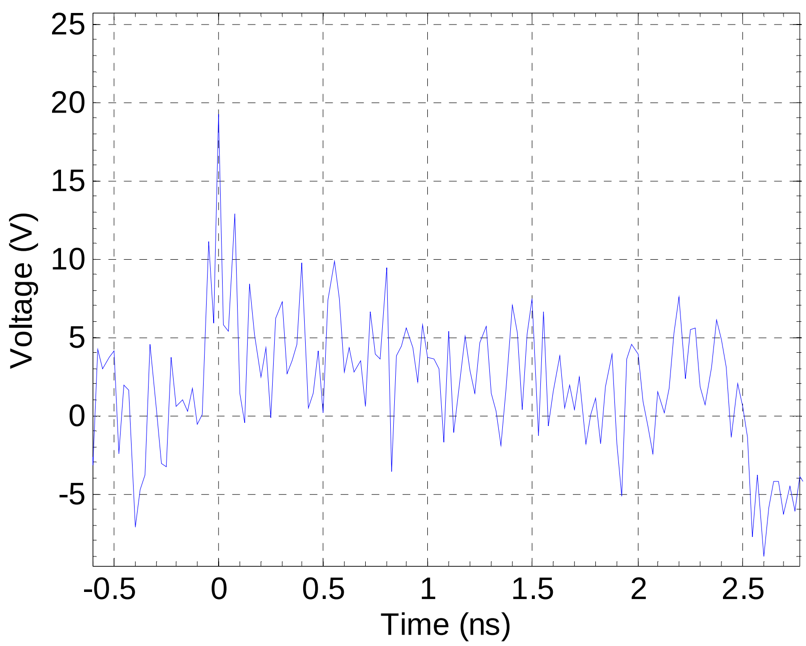
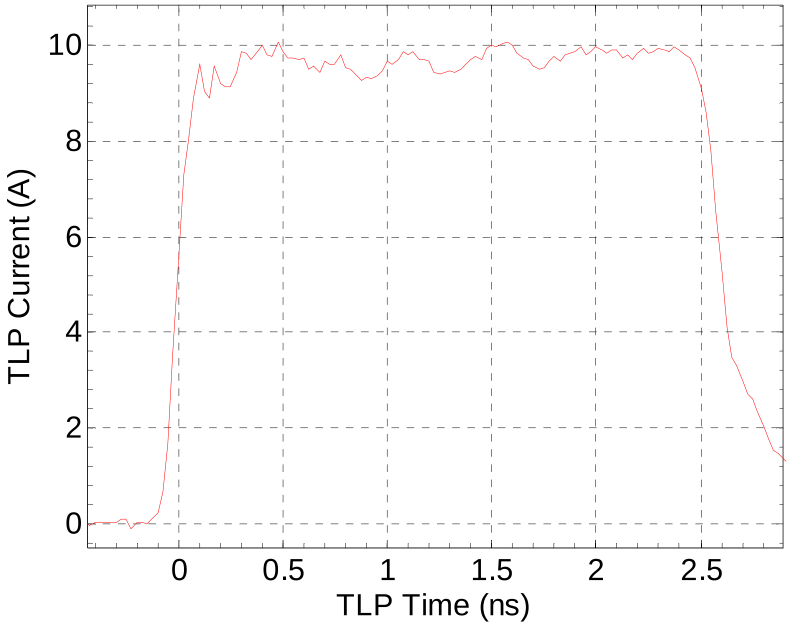
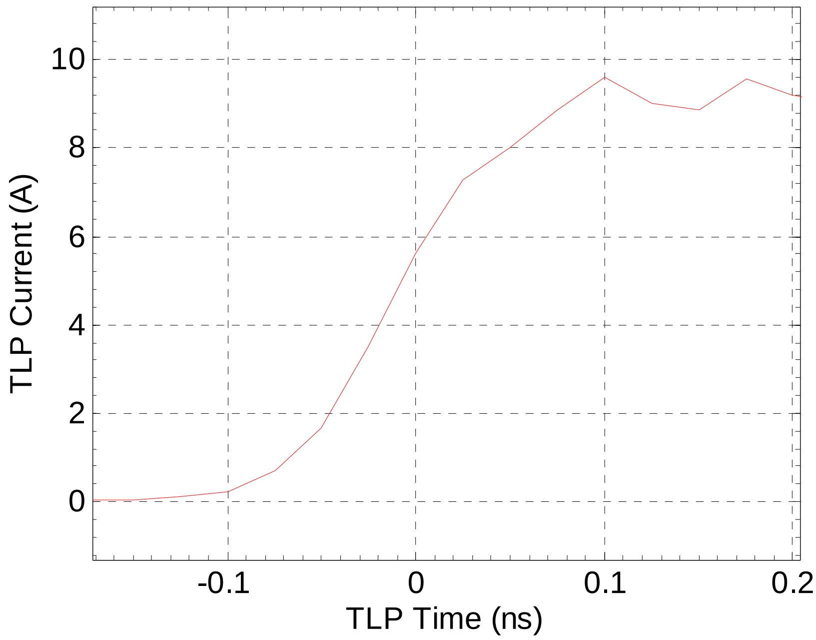


Figure 16: Transient voltage curve during a 2.5 ns, 100 ps rise time, 10 A pulse into the short. 10 pulses were averaged to decrease noise. In this plot the 0.25 Ω series resistance has not been subtracted.



(a) Current waveform.



(b) Current waveform: detail view of rise time.

Figure 17: Current waveform applied to the short circuit. The rise time is close to 100 ps (10-90 %).

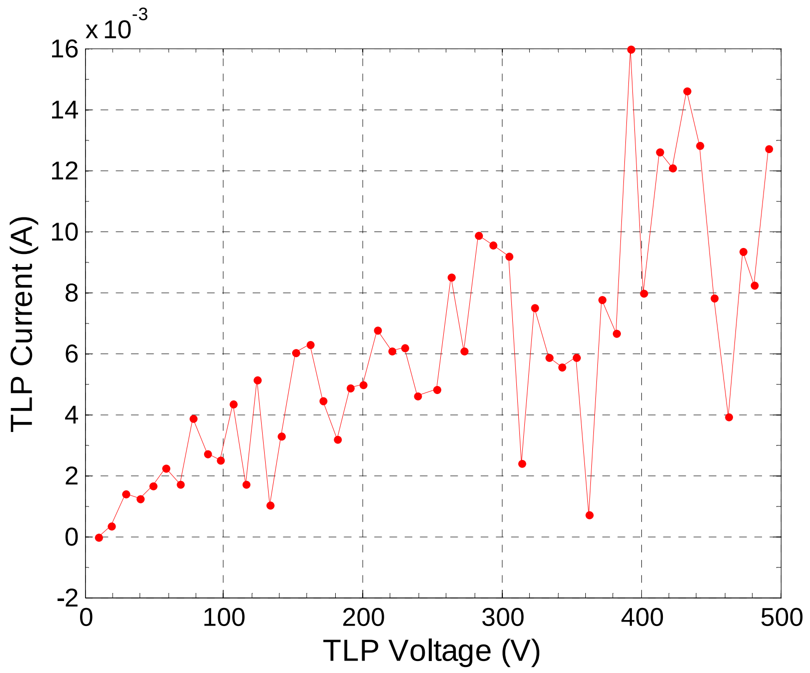


Figure 18: I-V curve measured over an open with a 2.5 ns wide pulse with 100 ps rise time. The data is averaged from 1 to 2.2 ns. **Note: y-axis shows milliamperes**.

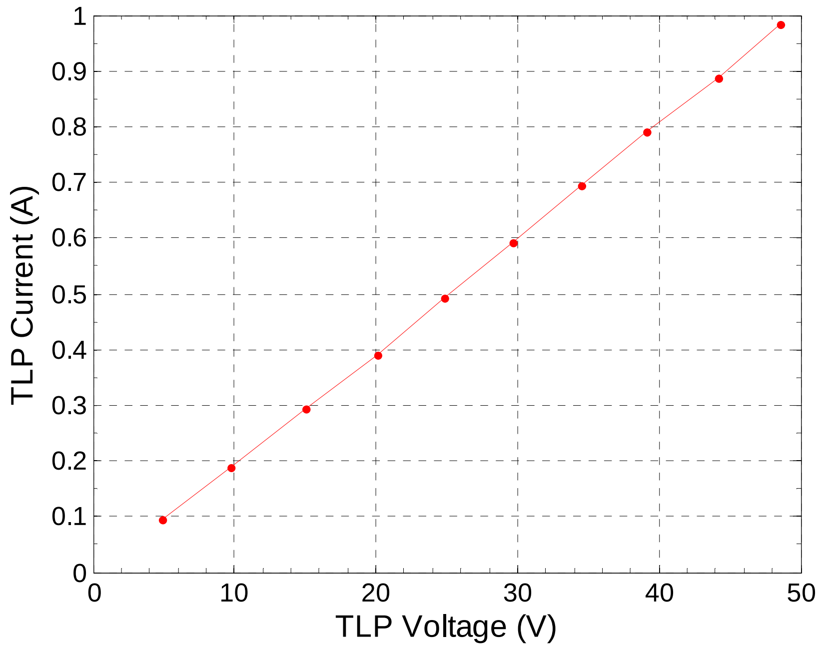


Figure 19: I-V curve measured over a 50 Ω load with a 2.5 ns wide pulse with 100 ps rise time. The data is averaged from 1 to 2.2 ns.