How to Use Picoprobes and Flexible Pitch Probes

Advanced TLP/HMM/HBM Solutions

This application note describes the four-wire (Kelvin) standard TLP method using a discrete current sensor, fixed-pitch and/or flexible-pitch probe tips.

1 Four-Wire (Kelvin) TLP Method

Fig. 1 shows the four-wire (Kelvin) TLP method including DC leakage measurement. This setup is widely used for standard TLP measurements with high accuracy because of separated pulse force and pulse sense channel. A transformer-based pulse current sensor (e.g. HPPI CS-0V5-A) is used in the pulse force channel. A tiny 4950 Ω resistor, which is integrated in front of the pulse sense probe tip, acts as voltage divider $100 : 1 = (4950\,\Omega + 50\,\Omega)/50\,\Omega$, with the 50 Ω transmission line and 50 Ω input impedance of the digital oscilloscope.

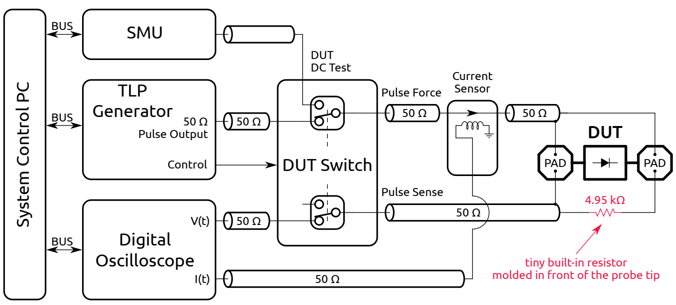

Figure 1: Four-wire (Kelvin) TLP method including DC leakage measurement

1.1 Why the Current Sensor Should Be Connected to the DUT as Close as Possible?

Fig. 2 is a simplified view of the block diagram shown in Fig. 1. The probe tips including equivalent circuit are shown in Fig. 9.

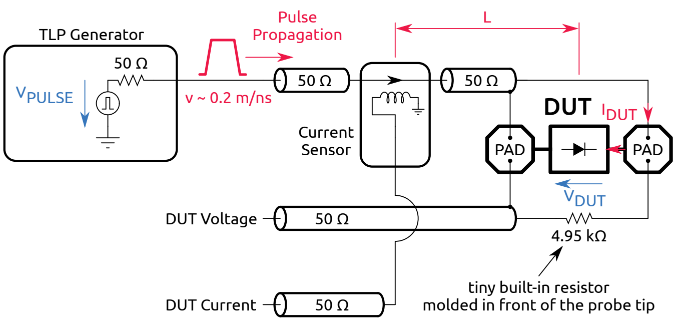

Figure 2: TLP generator, pulse force channel, voltage sense and current sense channel

L is the length of the 50 Ω interconnection cable between the transformer-based current sensor and the DUT. The propagation velocity of the pulse signal in the 50 Ω cable is approximately

$$v = \frac{c}{\sqrt{\epsilon_r}} \approx 0.2\,\mathrm{m/ns} \tag{1}$$

where the speed of light $c \approx 2.998 \cdot 10^8\,\mathrm{m/s}$ and $\epsilon_r \approx 2.1$ is relative dielectric constant of the e.g. PTFE-based insulator of the 50 Ω coaxial cable.

The readout of the current sensor is wrong in the time interval:

$$-\frac{L}{v} < t < +\frac{L}{v} \tag{2}$$

t	…	time in [ns]
L	…	distance between current sensor and DUT in [m]
v	…	$\approx 0.2\,\mathrm{m/ns}$ pulse propagation velocity

Let's investigate the following example test conditions:

1. Propagation velocity in the cable is $v \approx 0.2\,\mathrm{m/ns}$, according Eqn. 1
2. Distance L from DUT to current sensor (Fig. 2)
3. 100 ns pulse width, 100 ps rise time
4. TLP voltage is set to $V_{PULSE} = 1000\,\mathrm{V}$
5. Device-under-test (DUT) is a 5 Ω resistor

For this load condition we expect:

$$V_{DUT} = \frac{V_{PULSE}}{50\,\Omega + 5\,\Omega} \cdot 5\,\Omega = 90.9\,\mathrm{V} \tag{3}$$

$$I_{DUT} = \frac{V_{PULSE}}{50\,\Omega + 5\,\Omega} = 18.2\,\mathrm{A} \tag{4}$$

1.1.1 Test Case 1: $L = 0\,\mathrm{m}$

If $L = 0\,\mathrm{m}$, which means the current sensor is mounted directly at the DUT (which is not possible in reality), we would measure the following DUT voltage and current waveforms, as expected by Eqn. 3 and 4, confirmed by TLP simulation results[1] shown in Fig. 3.

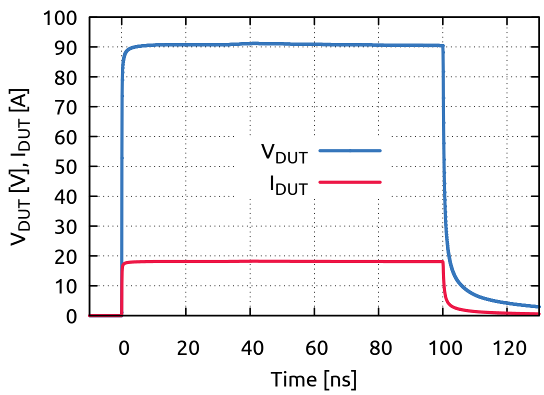

Figure 3: Simulated DUT waveforms with $L = 0\,\mathrm{m}$ condition

[1] TDR simulation of a TLP system including cable losses and rise time filter.

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Fig. 4 shows the same plot but with higher time resolution up to t = 20 ns.

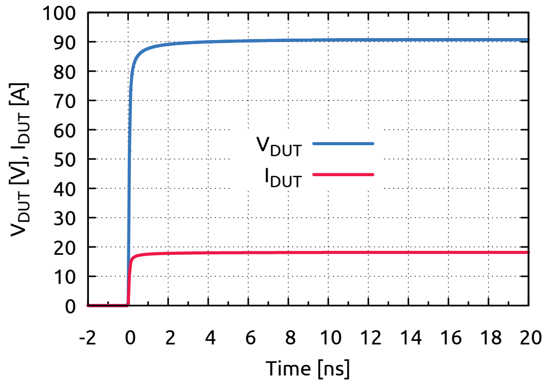

Figure 4: Simulated DUT waveforms with L = 0 m condition. Detail view up to t = 20 ns.

As a result, with L = 0, the voltage and current waveforms develop at $t > 0$ with expected value according Eqn. 3, Eqn. 4.

1.1.2 Test Case 2: L = 0.2 m

Now we assume L = 0.2 m, which means the current sensor is mounted 0.2 m far away from the DUT, as shown in Fig. 2. In this case we would measure the waveforms depicted in Fig. 5.

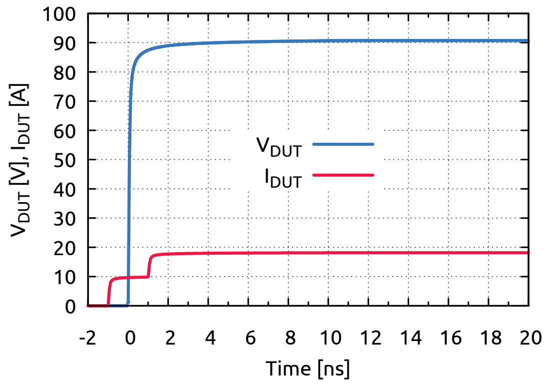

Figure 5: Simulated DUT waveforms with L = 0.2 m condition

At $t = -1$ ns the propagating pulse signal (Fig. 2) hits the current sensor first. Therefore, the readout of the current sensor at $[-1\,\text{ns} < t < 1\,\text{ns}]$ will result into

$$I(t)\Big|_{-1\,\text{ns}<t<1\,\text{ns}} = \frac{V_{\text{PULSE}}}{2 \cdot 50\,\Omega} = 10\,\text{A} \qquad (5)$$

At t = 0, the propagating pulse signal hits the DUT. Therefore, the expected voltage of V_{DUT} = 90.9 V develops, but the current senor does not recognize this event. The pulse signal is reflected at the DUT and needs to propagate back to the current sensor for another 1 ns. Only in case if incident and reflected pulse signals are available for superposition at the current sensor, we can expect the correct readout of the current sensor at $t > 1$ ns.

1.1.3 Test Case 3: L = 1 m

Now we assume L = 1 m to review the expected waveforms in Fig. 6.

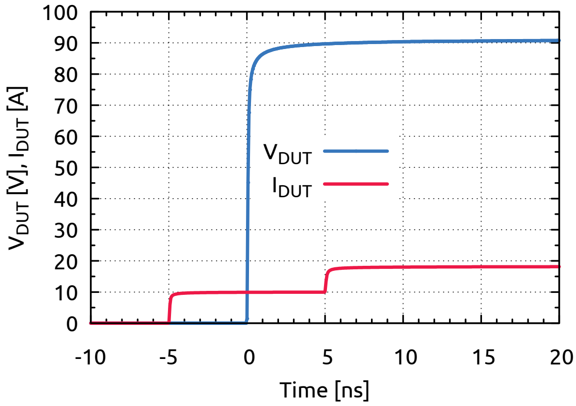

Figure 6: Simulated DUT waveforms with L = 1 m condition

The correct current readout occurs at $t > 5$ ns, as predicted by Eqn. 2.

1.1.4 Test Case 4: L = 0.2 m and Rise Time t_r = 10 ns

Finally, we assume L = 0.2 m and a TLP rise time of t_r = 10 ns instead of t_r = 100 ps of the previous test cases. In general the same effects occur as shown in Sect. 1.1.2 but the waveforms are filtered and delayed by the 10 ns rise time filter, which give a result as shown in Fig. 7. The current sensor readout signal is filtered by the rise time filter and the error becomes negligible.

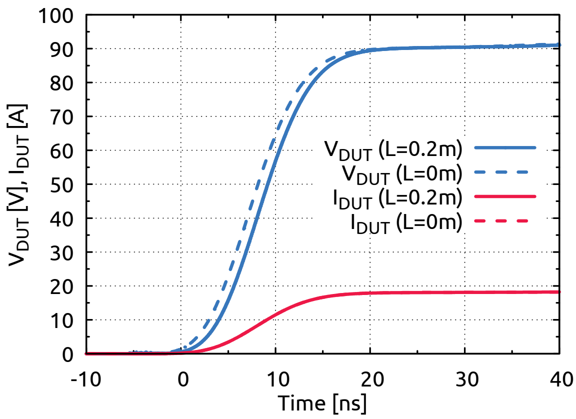

Figure 7: Simulated DUT waveforms with L = 0 m, 0.2 m and TLP rise time of t_r = 10 ns

1.1.5 Summary Test Cases

The previous investigations show, that it is recommended to mount the current sensor as close as possible nearby the DUT. L = 0.2 m is quite a good choice. Especially at a rise time of t_r = 10 ns the readout error becomes negligible.

2 Fixed-Pitch Probe Tips

Fig. 8 shows a typical fixed-pitch 200 µm probetip setup from GGB.

Please refer to https://ggb.com/home/model-10/ for the model 10 probe tip holder and description of replacement probe tips: https://ggb.com/wp-content/uploads/2017/06/mod10.pdf

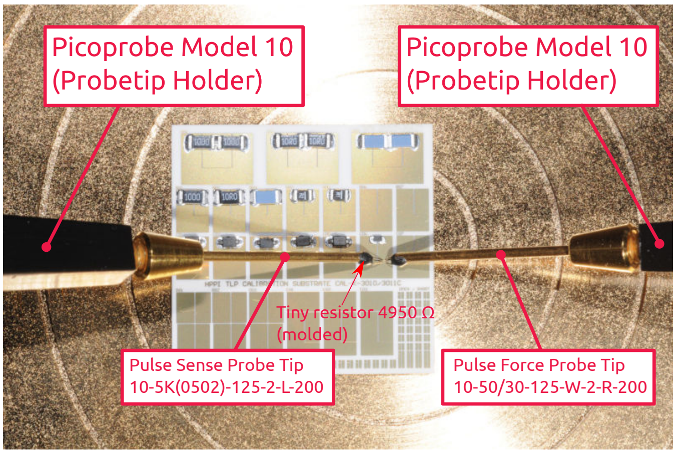

Figure 8: Fixed pitch picoprobes. Probing a reference device on the TLP calibration substrate.

Fig. 9 shows the detail view of Fig. 8 including the equivalent circuit of the GS-type (ground-signal) probe tips (see also Fig. 2). On the left sided probe tip clearly the molded resistor can be identified. The mold compound is a little bit larger in comparison to the right sided 50 Ω probe tip without built-in resistor.

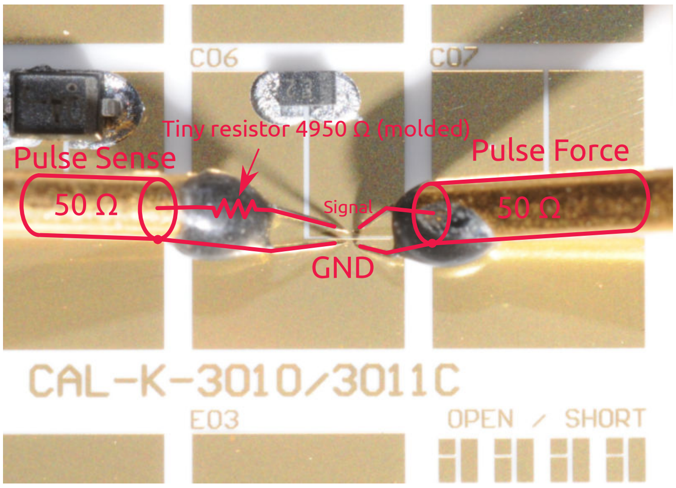

Figure 9: Fixed pitch picoprobes. Probing a reference device on the TLP calibration substrate. Detail view of Fig. 8 including equivalent circuit of the probe tips.

In general, the fixed-pitch setup is preferred for improved signal integrity.

3 Flexible-Pitch Probe Tips

Sometimes the fixed-pitch is a limitation, in case of devices to be measured changes often and have different pad pitch and dimensions. For these cases the flexible-pitch setup has been developed:

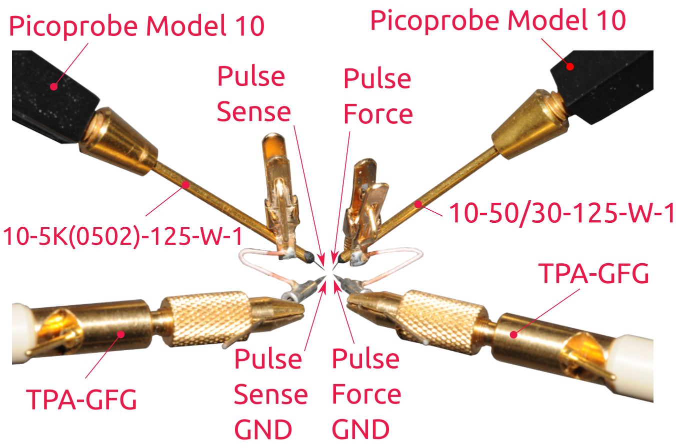

Figure 10: Flexible pitch setup using GGB 10-50/30-125-W-1 (pulse force) and GGB 10-5k(0502)-125-W-1 (pulse sense) replacement probe tips and GF-A flexible pitch ground fixture

The 10-50/30-125-W-1 (pulse force) and 10-5k(0502)-125-W-1 (pulse sense) probe tips have a center conductor/needle but no ground needle. The ground contact is made using a clamp, short flexible wire, nozzle for a 0.5 mm needle and a separate probe arm for the ground needle. Despite the ground connection using a clamp with wire the pulse signal quality remains very good for rise times as fast as 200 ps.

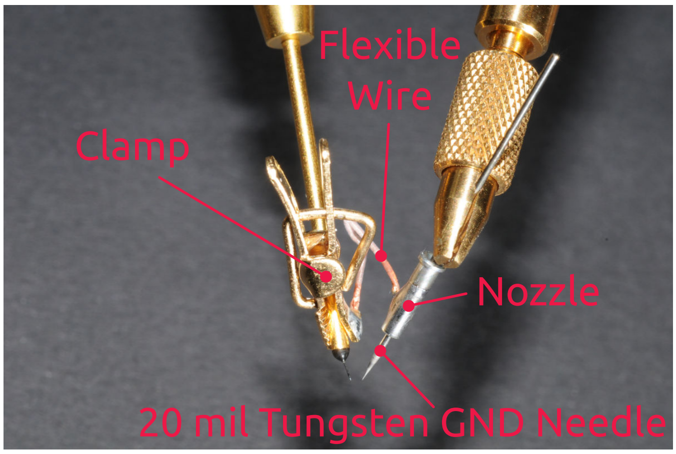

Figure 11: Ground fixture GF-A / 15 mm assembly: clamp, flexible wire and nozzle including 20 mil (0.508 mm) tungsten GND needle

Fig. 11 shows the ground fixture comprising the clamp, flexible wire and nozzle including 0.5 mm tungsten needle. The clamp needs to be fixed on the picoprobe tip. The tungsten needle shall be mounted on a separate DC probe arm including micropositioner.

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