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Introduction to Transmission Line Pulse (TLP)

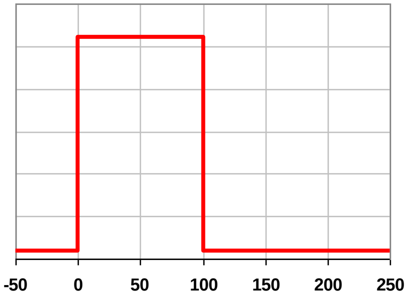
The world leader in serving science

Overview

1. What is TLP
2. How TLP works
3. TLP measurement
4. TLP variants
5. Interpreting TLP data
6. TLP Precision
7. VF-TLP
8. Q&A

History

- Transmission Line Pulse
  - Introduced as a possible method to emulate energy in HBM
  - Determined that for a given peak current, a TLP pulse of 100ns carries the same energy as HBM
    - Same energy is produced by different voltages:
      - 50V TLP = 1A
      - 1500V HBM = 1A



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Background

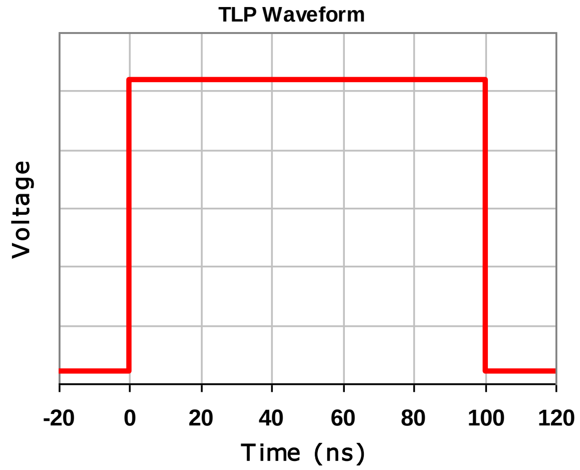
- Characterization of protection structures is important
  - Predict behavior for real world events
- Important parameters:
  - Snapback voltage
  - Turn on time
  - R_{ON} resistance
  - Failure point
- Must determine parameters with techniques similar to ESD
- TLP is an excellent solution
  - Controlled impedance makes measurements easier
  - Low duty cycle prevents heating

What is TLP

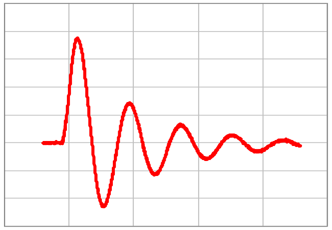
Section 1: What is **TLP**

- What makes **TLP** different than **ESD**?

  - **ESD** tests simulate real world events
    - HBM, MM, IEC, CDM
  - **TLP** does not simulate any real-world event

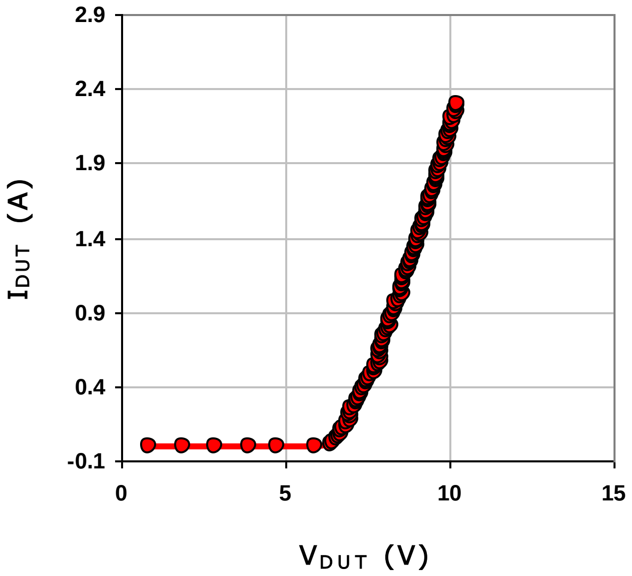


  - **ESD** tests record failure level
    - “Qualification”
  - **TLP** tests record failure level *and* device behavior
    - “Characterization”



Section 1: Device Characterization

- What is Device Characterization?
  - Describes the resistance of a device for a given stimulus
    - Resistance = Voltage / Current
  - Conventionally performed by increasing amplitude until failure

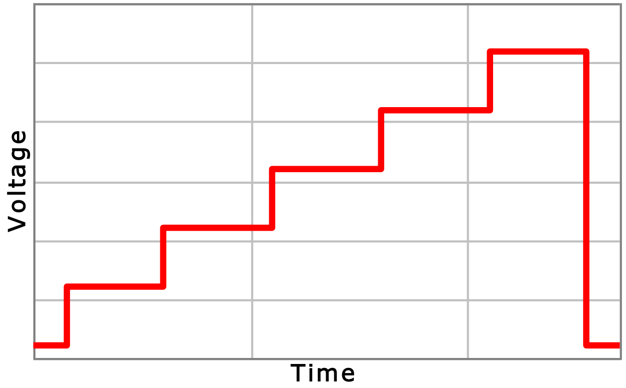


  - Like Curve Tracing

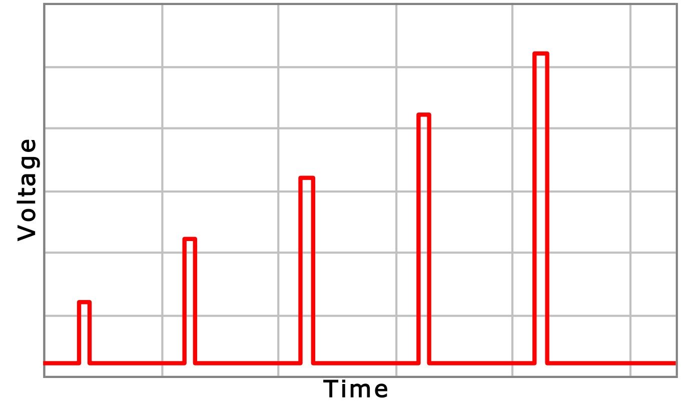
Section 1: Device Characterization

- How is **TLP** *different* than Curve Tracing?

- **Curve Tracing** is DC



- **TLP** is a short pulse

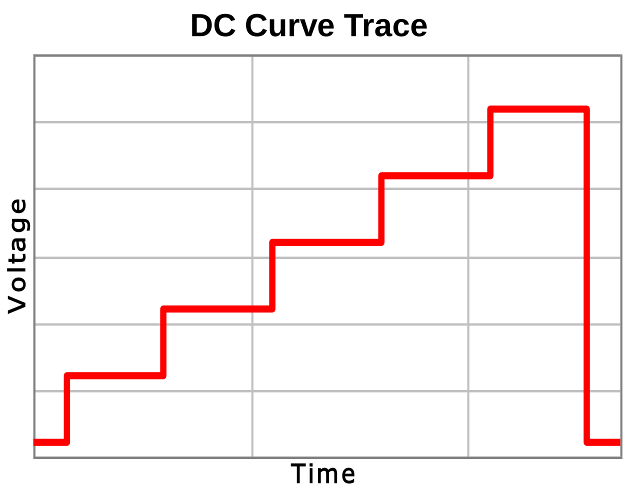


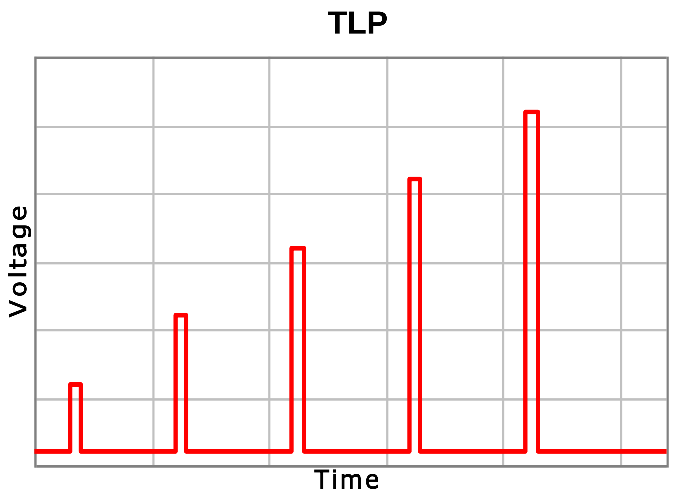
- Shorter pulse
  - Reduced duty cycle, less heating

- Controlled Impedance
  - Allows device behavior to be observed (more on this later)

Section 1: Device Characterization

- How is **TLP** *the same* as Curve Tracing?

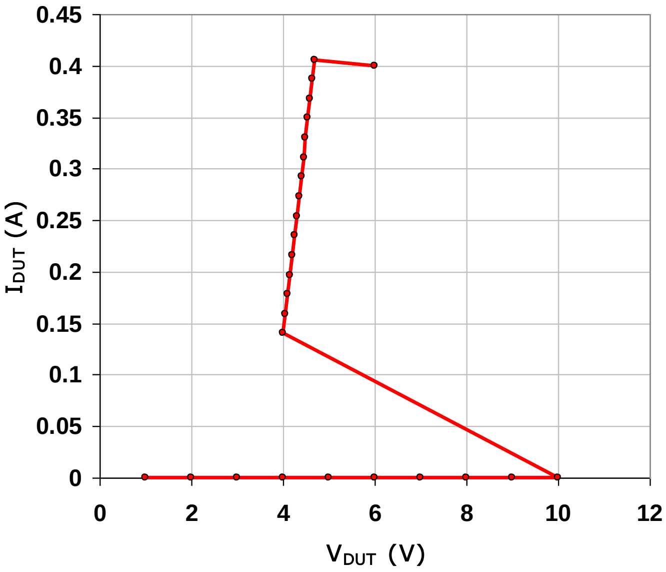




- Measure resistance of device with increasing voltage
  - Less heat means higher voltage before failure

Section 1: Device Characterization

- What can I learn from Device Characterization with **TLP**?
  - Turn-on time
  - Snapback voltage
  - Performance changes with rise time



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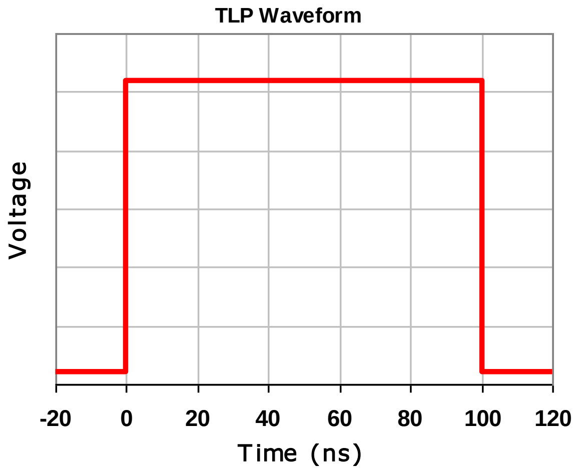
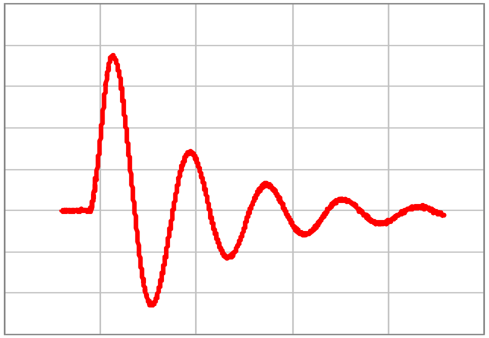
Section 1: TLP Waveforms

- What does a TLP waveform look like?
  - Square pulse



  - Unlike ESD waveforms, TLP does not mimic any real world event

HBM Waveform



MM Waveform

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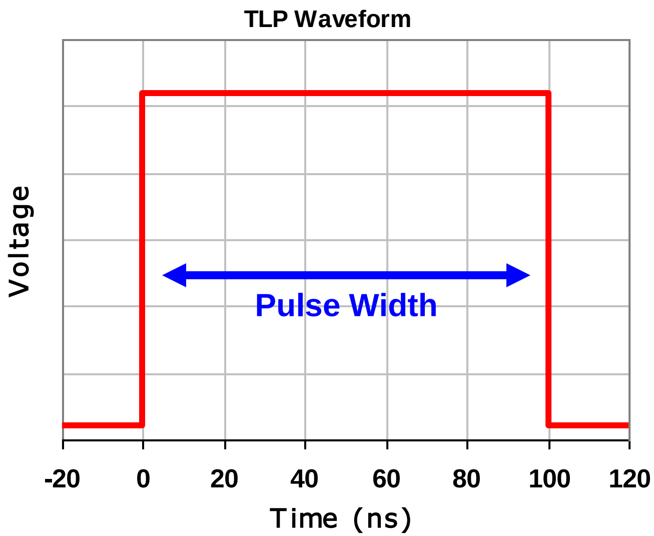
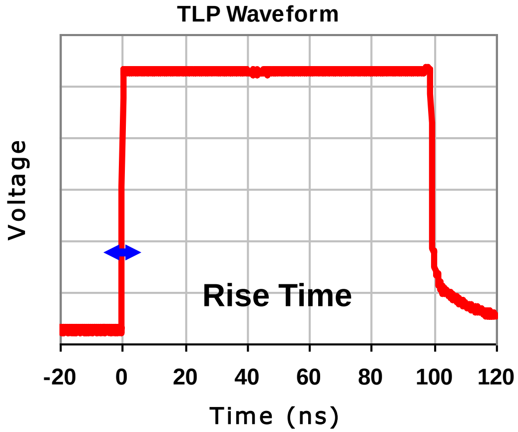
Section 1: TLP Waveforms

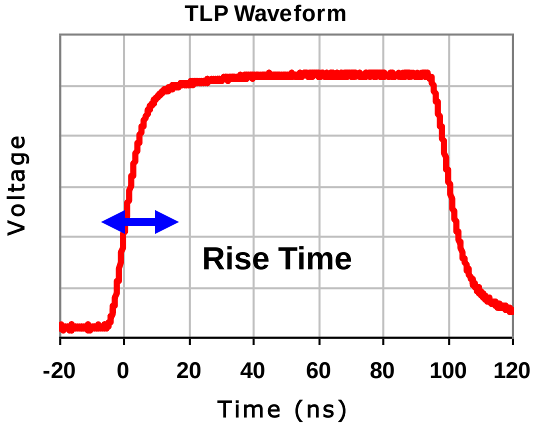
- What variations are there for TLP waveforms

  - Pulse Width
    - 100ns
    - 30ns – 500ns
    - VF-TLP: 1ns – 10ns



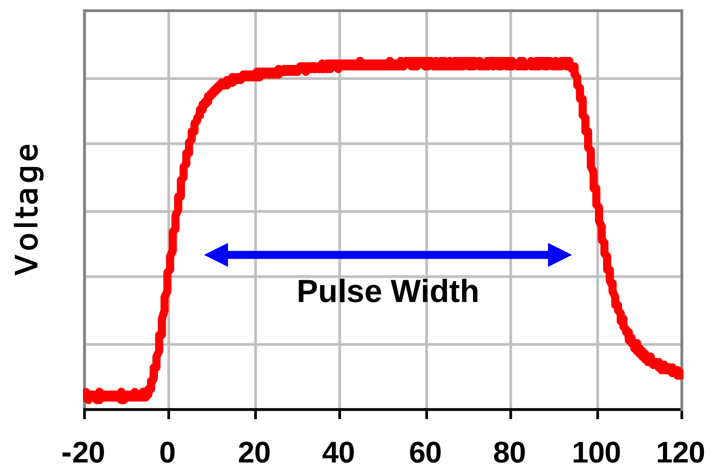
  - Rise Time
    - 0.2ns – 10ns



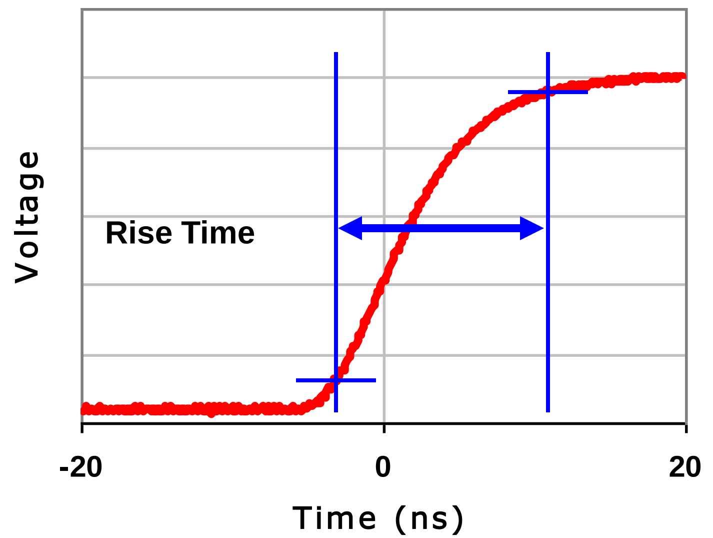


Section 1: TLP Waveforms

- How do these variations affect the **TLP** test?
  - Pulse Width
    - Energy under the curve



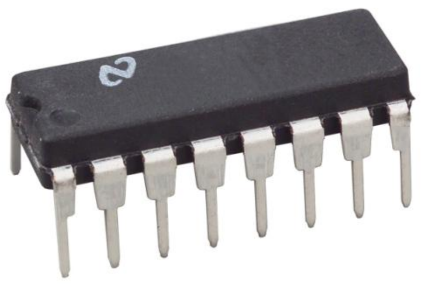
  - Rise Time
    - Device reaction



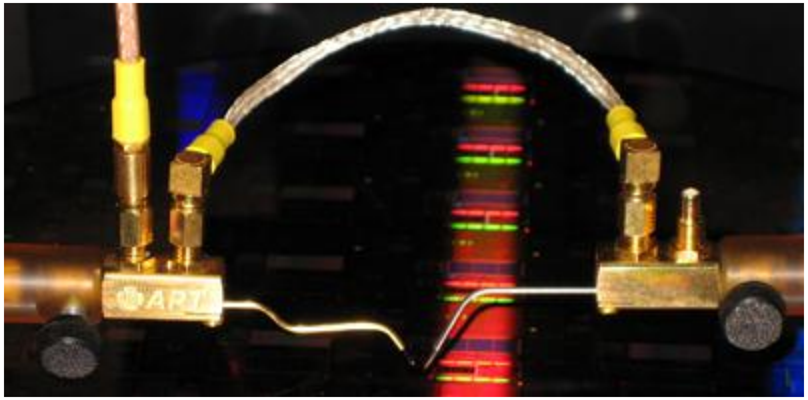
Section 1: Devices for TLP Testing

- What kinds of packages can be tested?

  - Package Level



  - Wafer Level

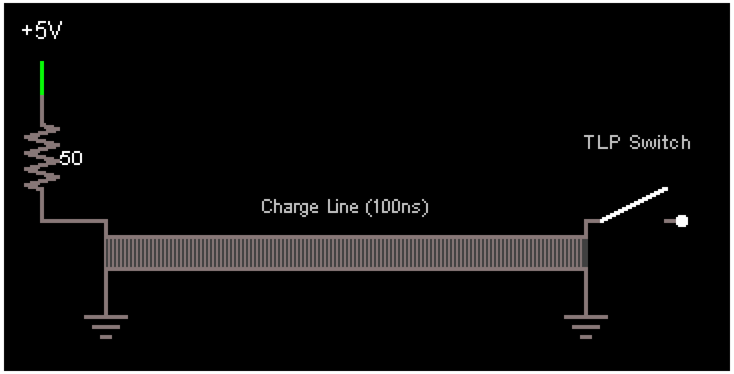


How TLP Works

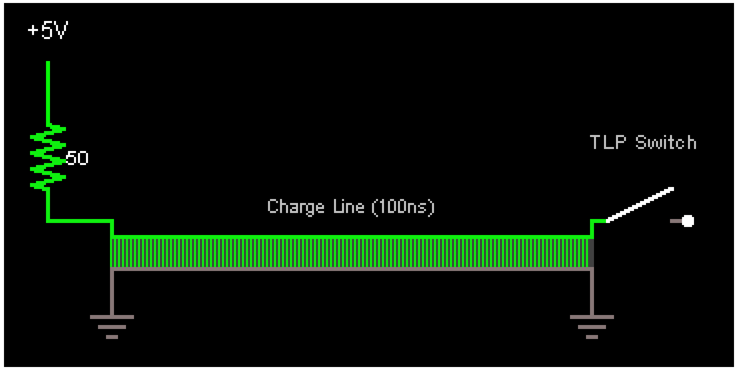
- How TLP pulses are generated

Section 2: How TLP Works

- How is a TLP waveform generated?
  - **Transmission Line** connected to power supply
    - Called **Charge Line**
    - Length proportional to pulse width

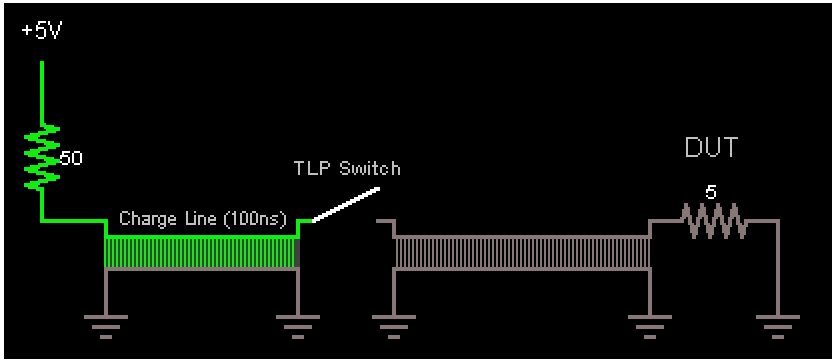


  - Power supply charges the cable

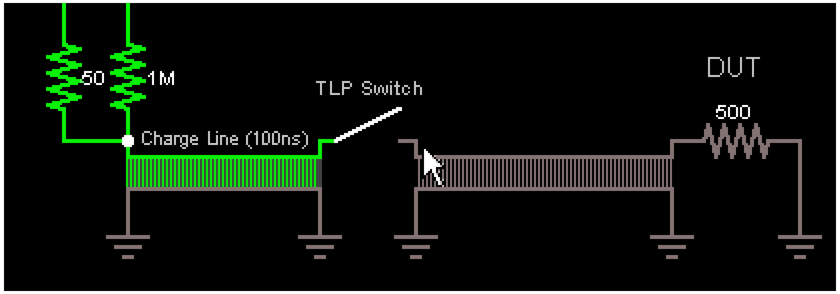


Section 2: How TLP Works

- How is a TLP waveform generated?
  - **DUT** lies at end of another transmission line



  - Switch closes
    - Charge exits **Charge Line**, propagates towards DUT



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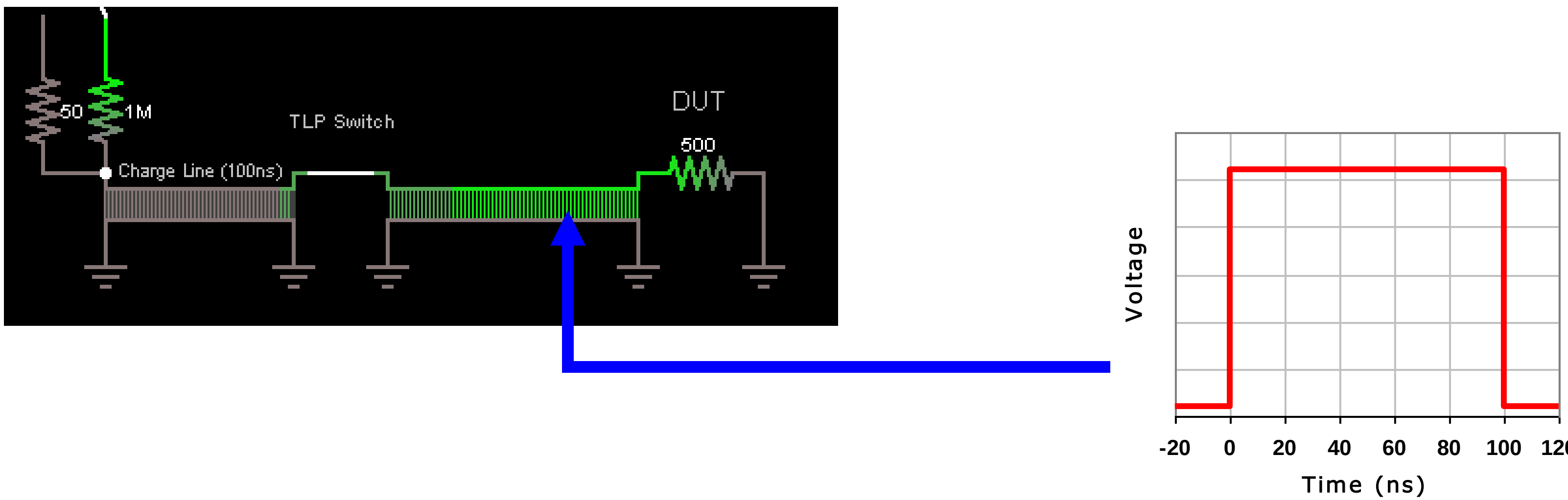
Section 2: How TLP Works

- How is a TLP waveform generated?
  - Square waveform
    - **Charge Line** behaves as a storage device



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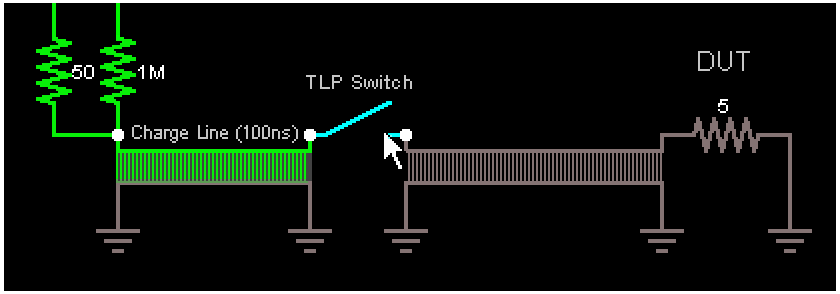
Section 2: How TLP Works

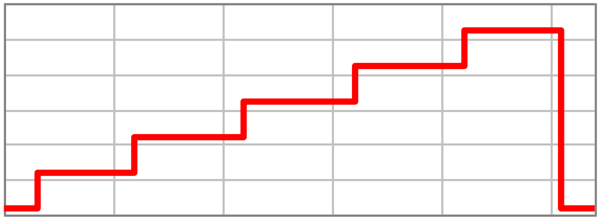
- What happens when the waveform hits the DUT?
  - Recap: TLP is a short-duration pulse in a controlled-impedance environment
    - Behaves like an RF signal
  - RF signal behavior
    - Propagates until impedance changes



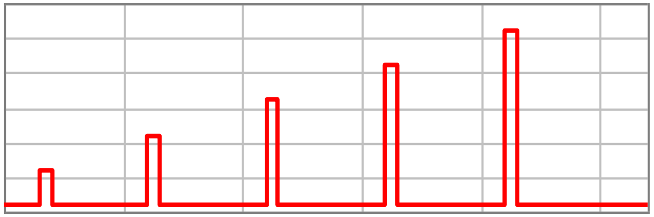
Section 2: How TLP Works

- How is resistance measured with a TLP pulse?
  - Square pulse, perceive it as a short-duration Curve Trace

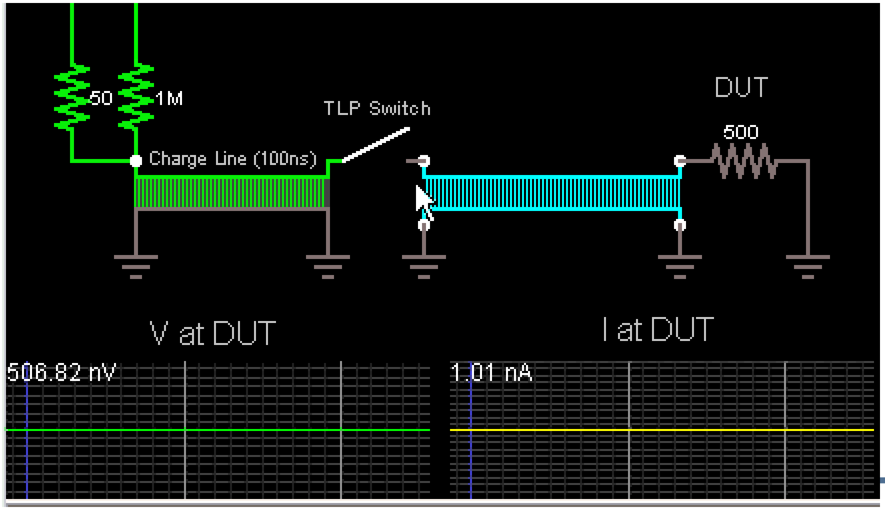
DC Curve Trace



TLP



  - Voltage and Current probes measure the DUT



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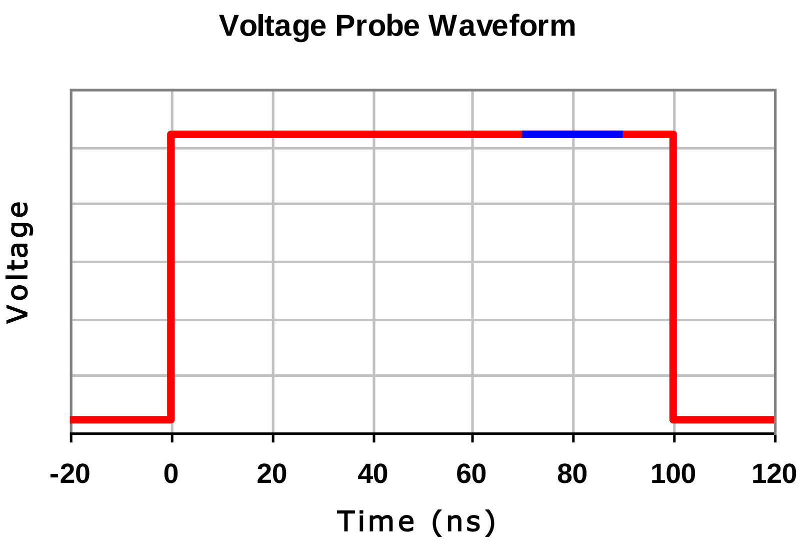
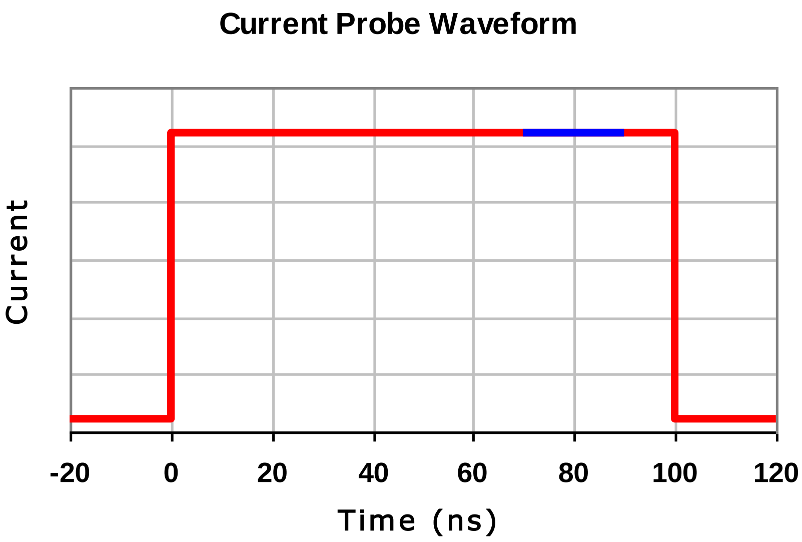
Section 2: How TLP Works

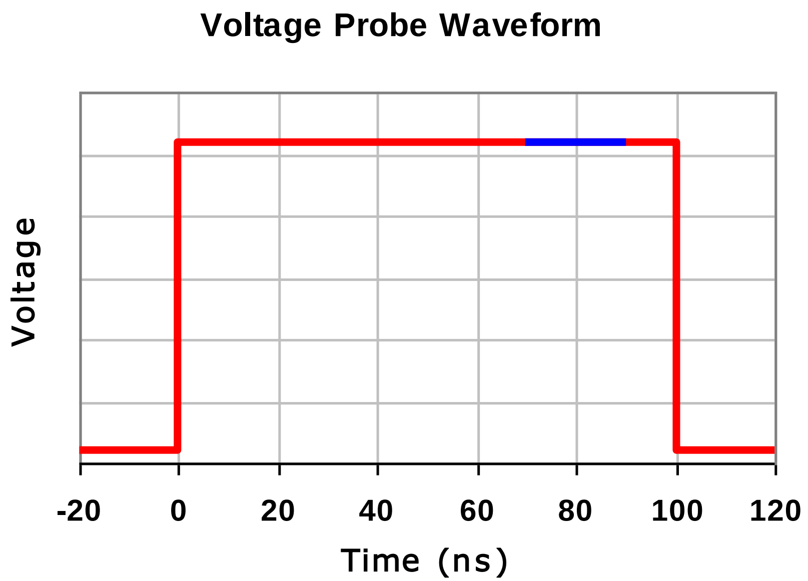
- How is resistance measured with a TLP pulse?
  - Plateau of waveforms are averaged
    - Device allowed to settle into “quasi-static” state

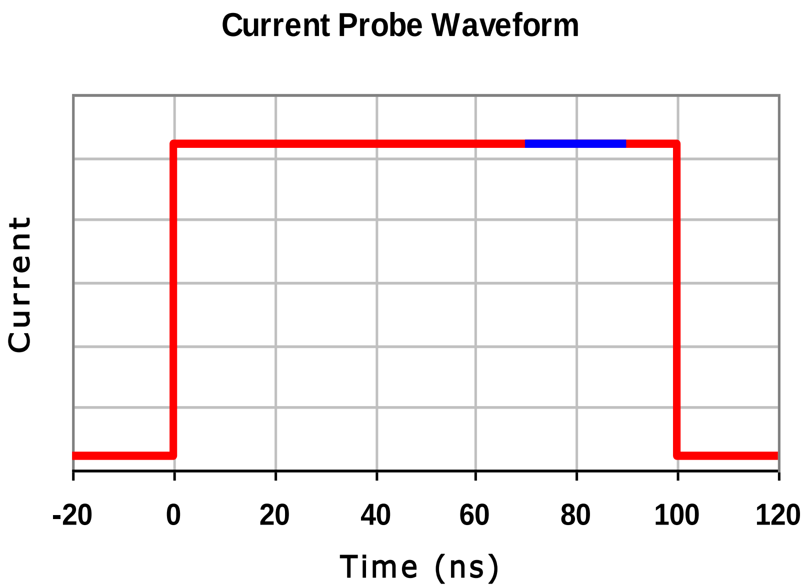




Section 2: How TLP Works

- Why use both a Voltage probe and a Current probe?





- It is possible to calculate DUT resistance with only 1 probe
  - $V_{DUT} = V_{Pulse} - (I_{DUT} * Z_{TLP})$
  - $I_{DUT} = (V_{Pulse} - V_{DUT}) / Z_{TLP}$
- Not desirable because extremes are noisy

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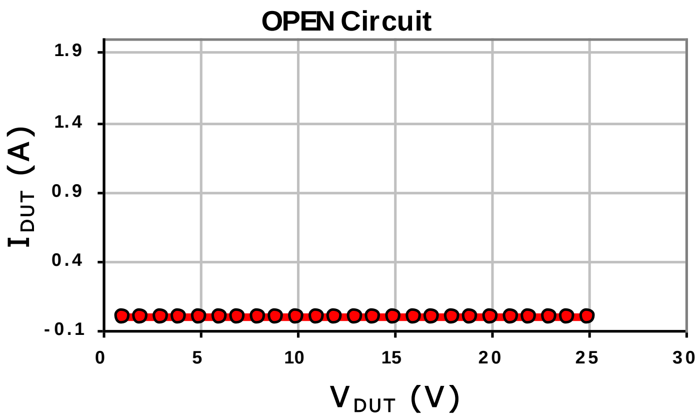
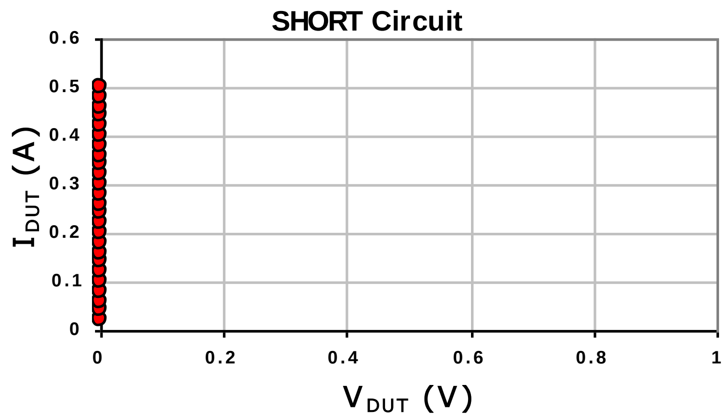
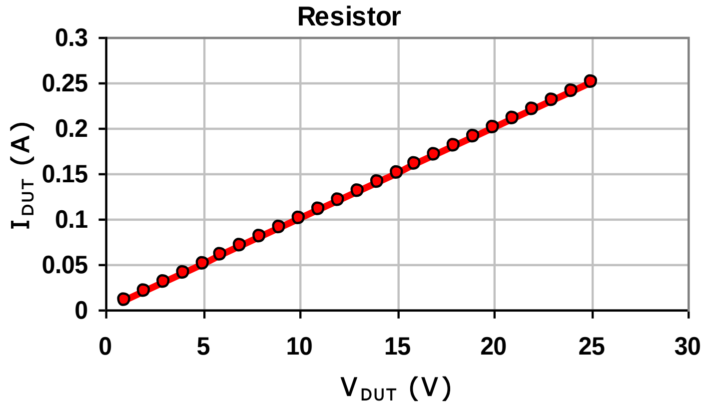
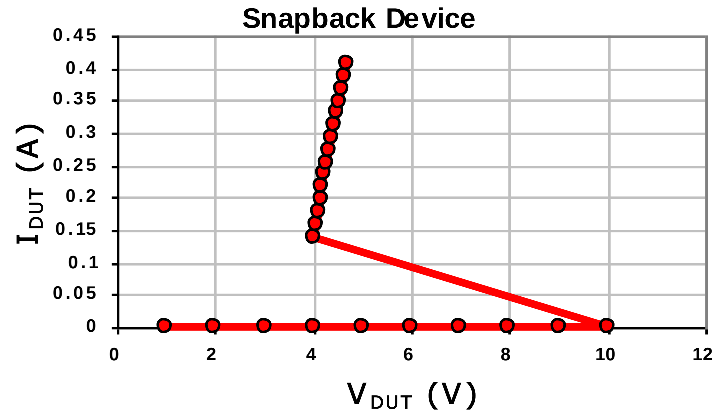
Section 2: How TLP Works

- Sequential TLP pulses produces an I/V Curve









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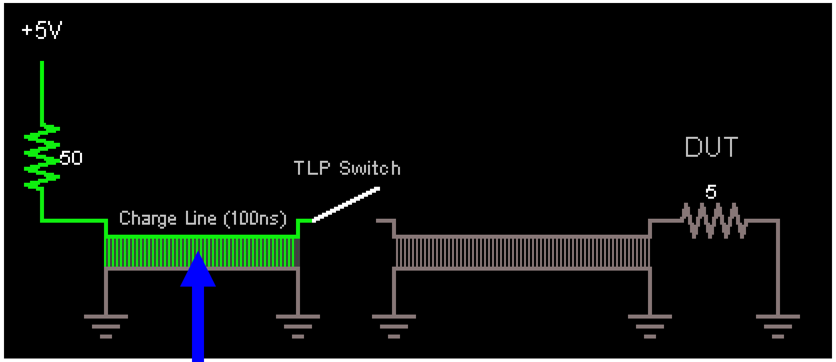
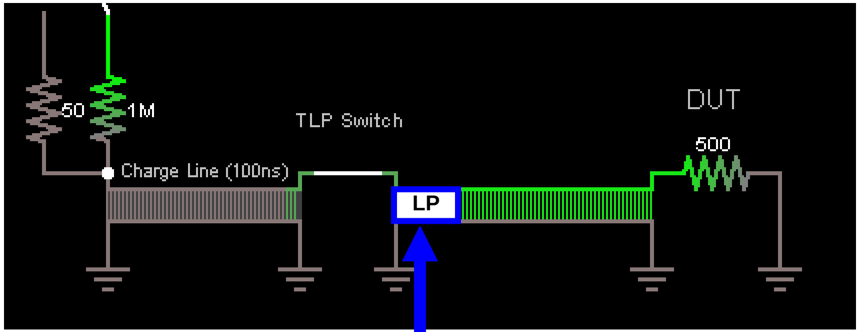
Section 2: How TLP Works

- How is the **Pulse Width** changed?
  - Length of cable



- How is the **Rise Time** changed?
  - Low-pass filter added

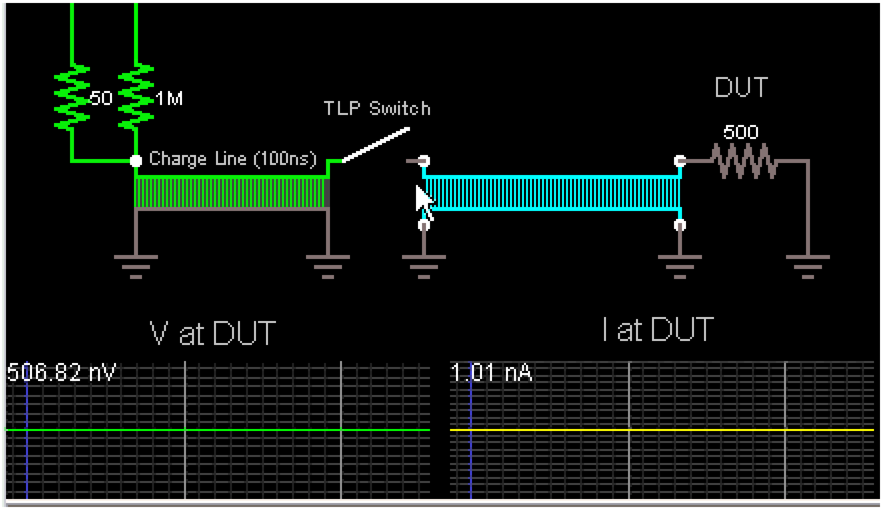


TLP Measurement

- How devices are measured

Section 3: TLP Measurement

- Measurement Goals
  - Capture Voltage at the DUT
  - Capture Current through the DUT



Section 3: TLP Measurement

- Equipment to capture V and I

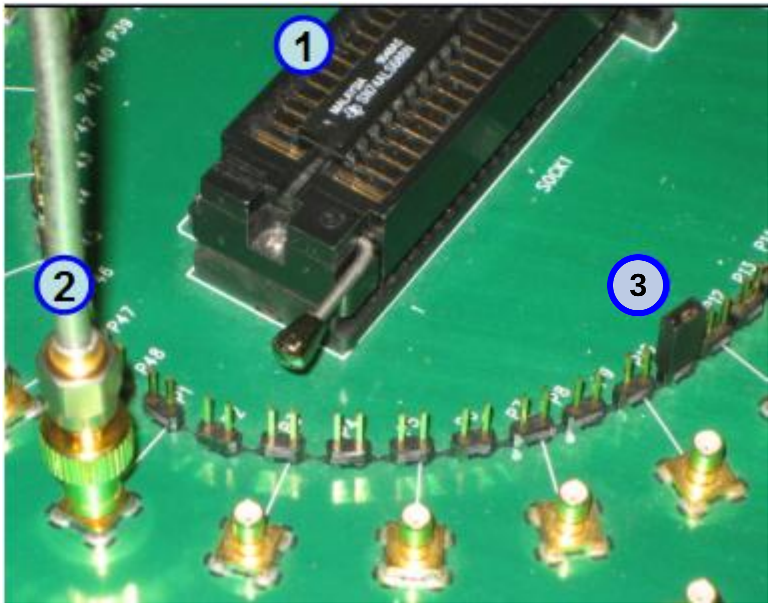
Voltage Probe

Current Probe

Oscilloscope

Section 3: TLP Measurement

- Equipment to deliver TLP pulse to DUT

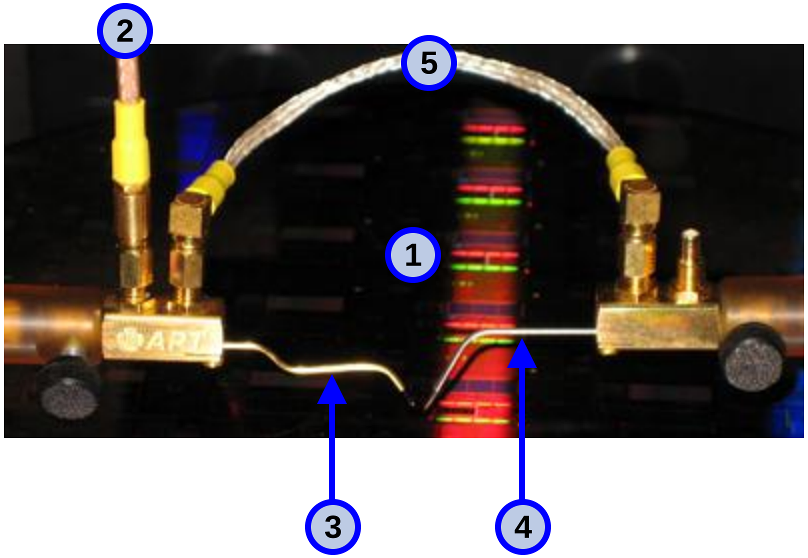


Package Level

1. DUT in socket
2. TLP Pulse delivery cable
3. Grounded pin

Wafer Level

1. DUT (on wafer)
2. TLP Pulse delivery cable
3. TLP Pulse delivery probe
4. Ground Probe
5. Ground Braid



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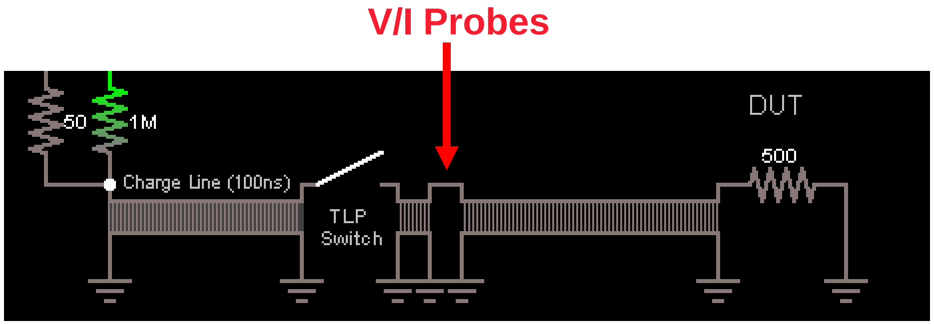
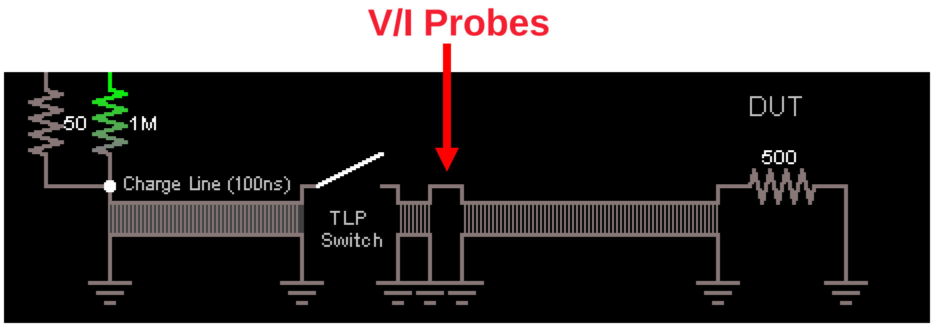
Section 3: TLP Measurement

- Ideally, V and I probes are directly on DUT
  - Direct placement not possible



Section 3: TLP Measurement

- Although probes are not at DUT, measurements are possible

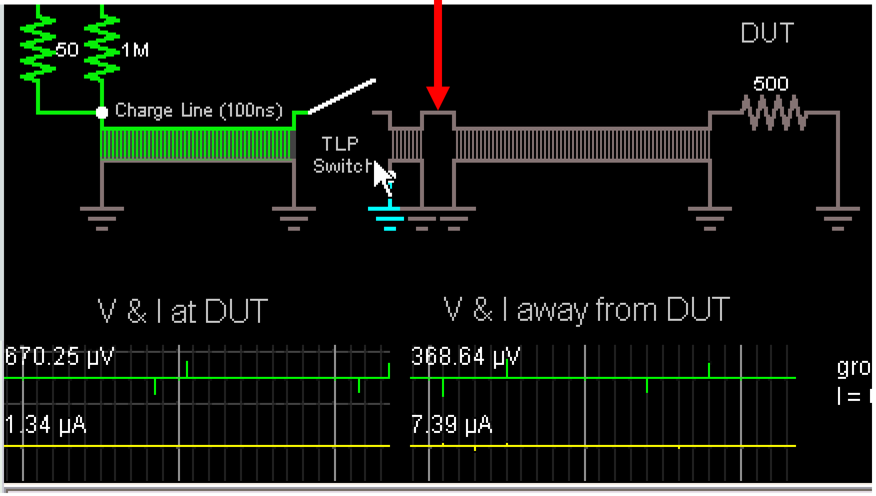


- Controlled impedance
- Waveform observable any place along path
- Time Domain Reflection (TDR)

Section 3: TLP Measurement

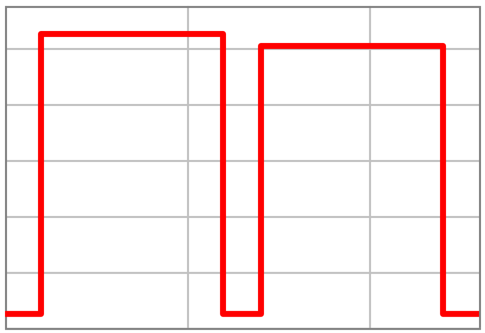
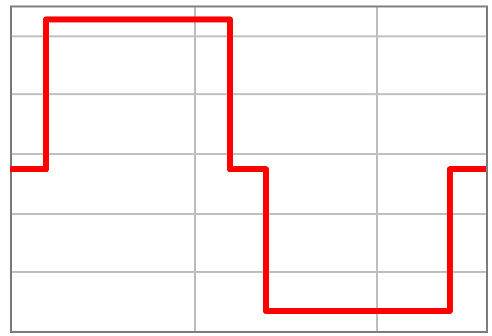
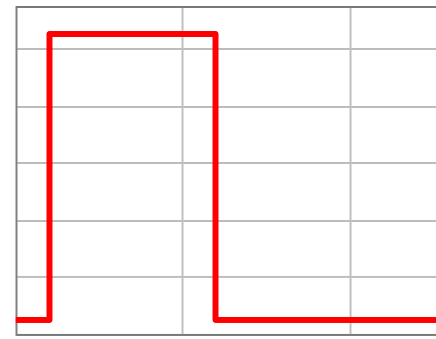
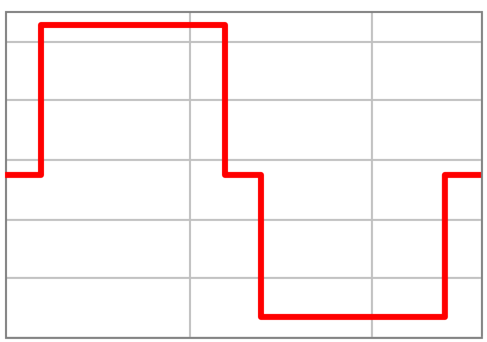
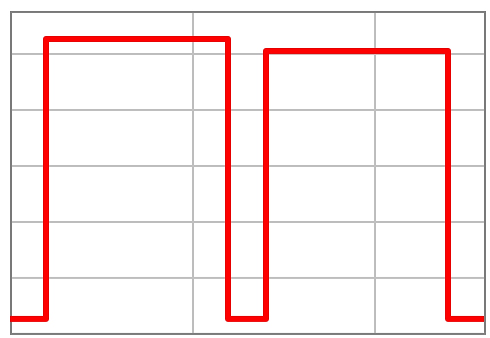
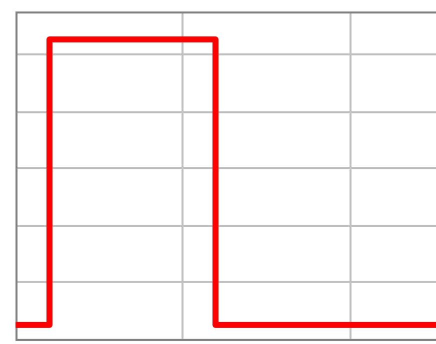
- How are measurements accomplished away from DUT?

V/I Probes



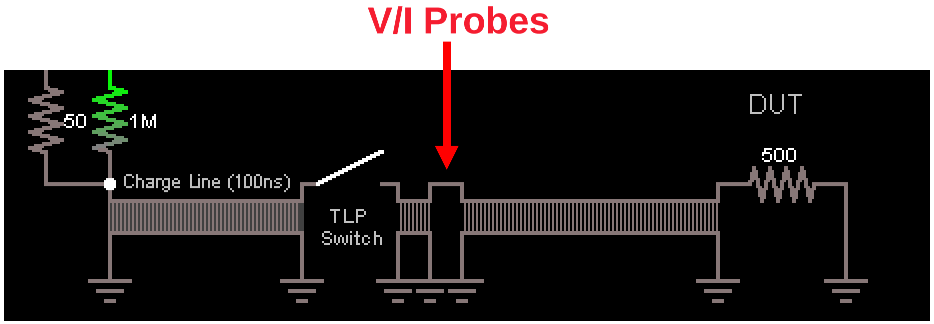
- **Incident** and **Reflected** waveforms
- Adding the waveforms reproduces DUT measurement
- Incident and Reflected waveforms are recorded separately (TDR-S)

Section 3: TLP Measurement

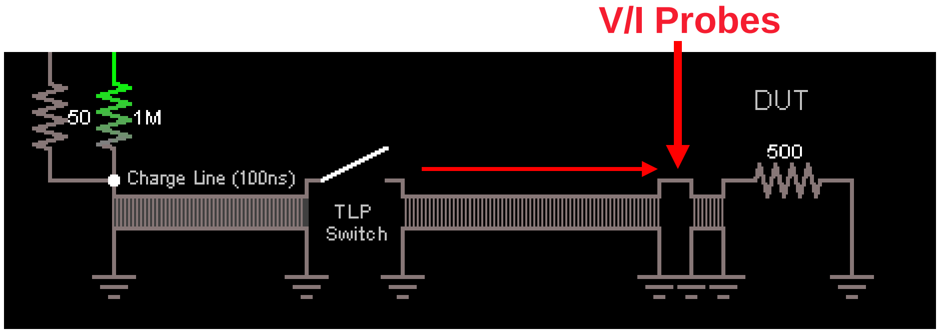
Reflected Waveform Polarity	DUT Ω > Z_{TLP} (Example: Open Circuit)	DUT Ω < Z_{TLP} (Example: Short Circuit)	DUT Ω = Z_{TLP} (Example: 50 Ω Resistor)
Voltage Waveform	Positive Reflection 	Negative Reflection 	No Reflection 
Current Waveform	Negative Reflection 	Positive Reflection 	No Reflection 

Section 3: TLP Measurement

- TDR-S performs waveform addition with software

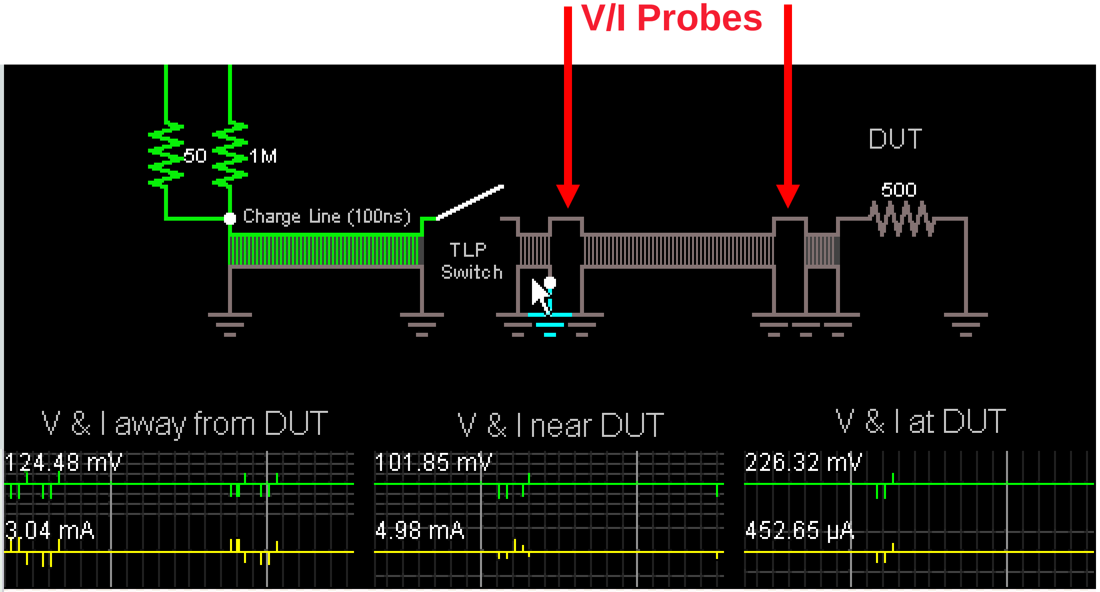


- Waveform addition can also be done in the TLP circuit



Section 3: TLP Measurement

- Overlapping waveforms



  - **Incident** and **Reflected** overlap, add together
  - Overlapped waveform plateau reproduces DUT waveform

TLP Variants

Section 4: Importance of Impedance

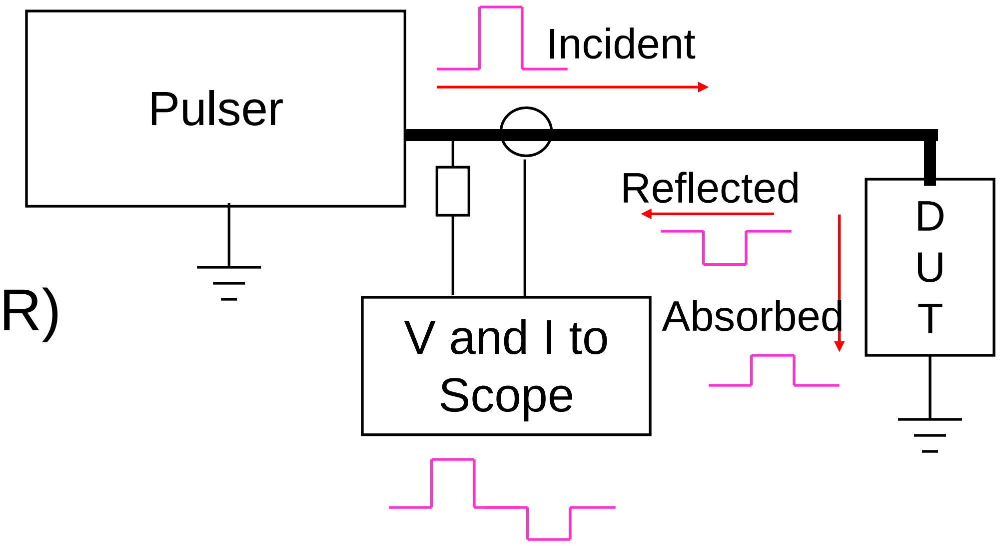
- Why vary the impedance?

- Low Impedance
  - More current flow for a given voltage
  - More voltage amplitude

- High Impedance
  - Less current flow for a given voltage
  - Less voltage amplitude

Section 4: TLP Variants

- TLP circuit characteristics up to this point
  - 50 Ω Impedance
  - One stress-pin
  - One ground-pin

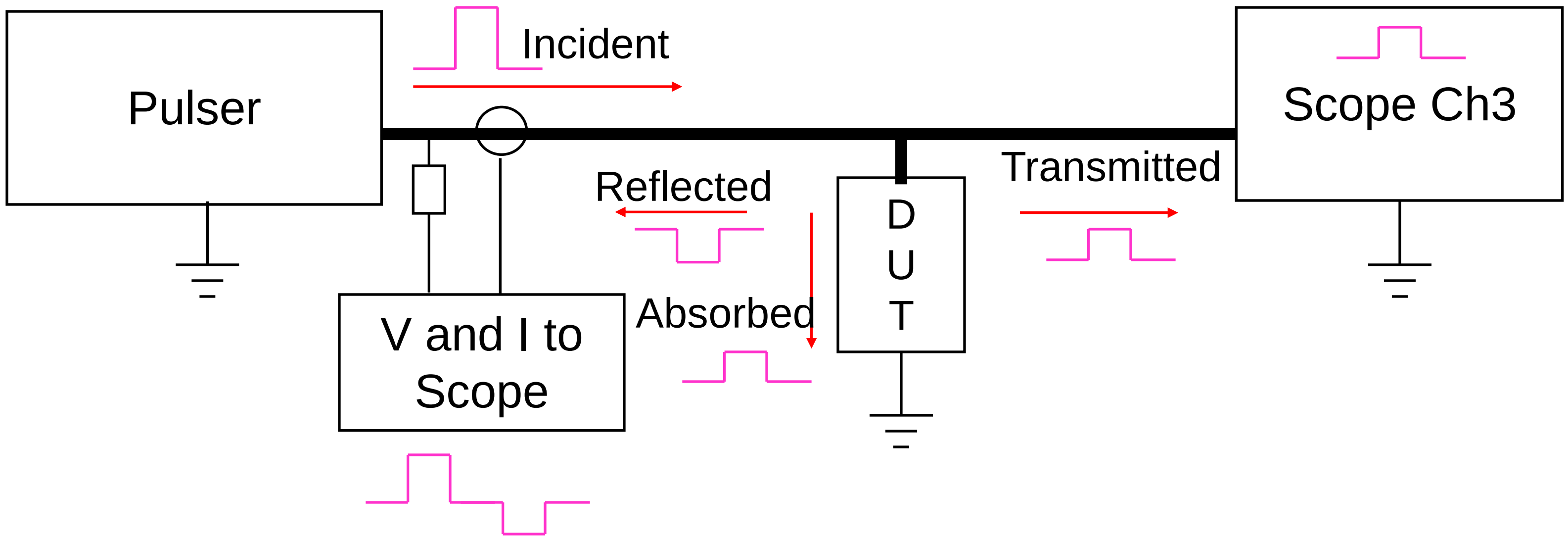


- Time Domain Reflection (TDR)
  - TDR-O
  - TDR-S

- Variations alter the system impedance and grounding style

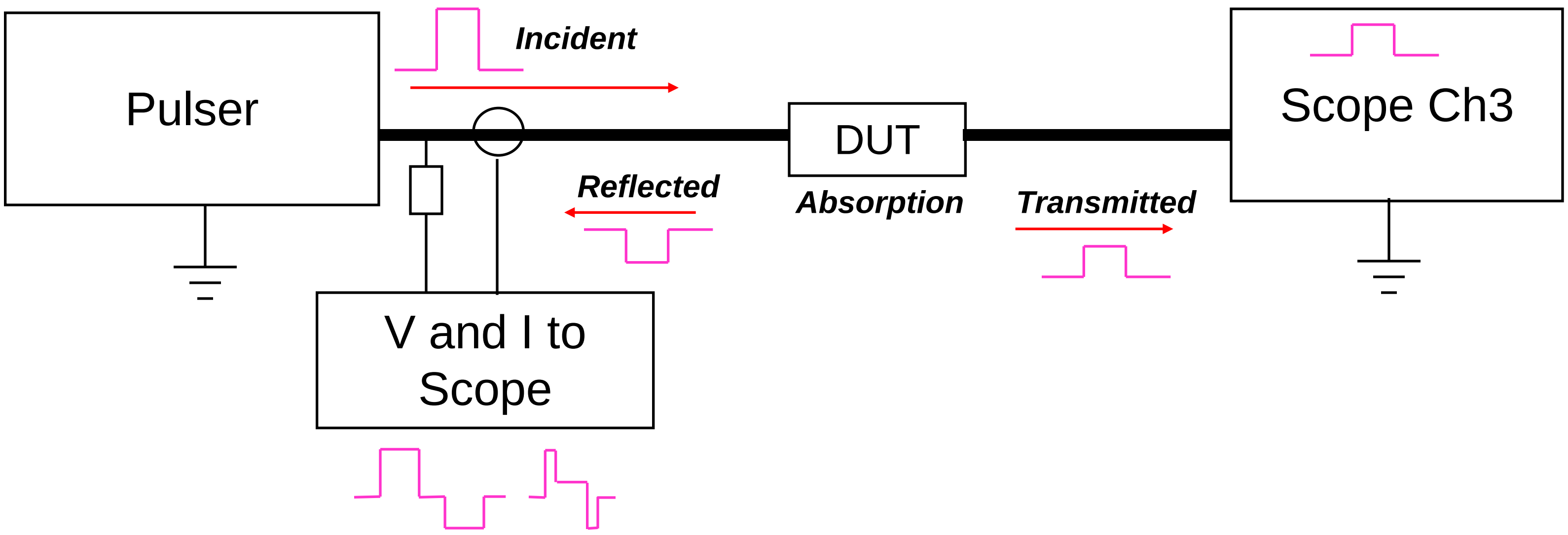
Section 4: TLP Variants

- Time Domain Transmission (TDT)
  - 25Ω system impedance



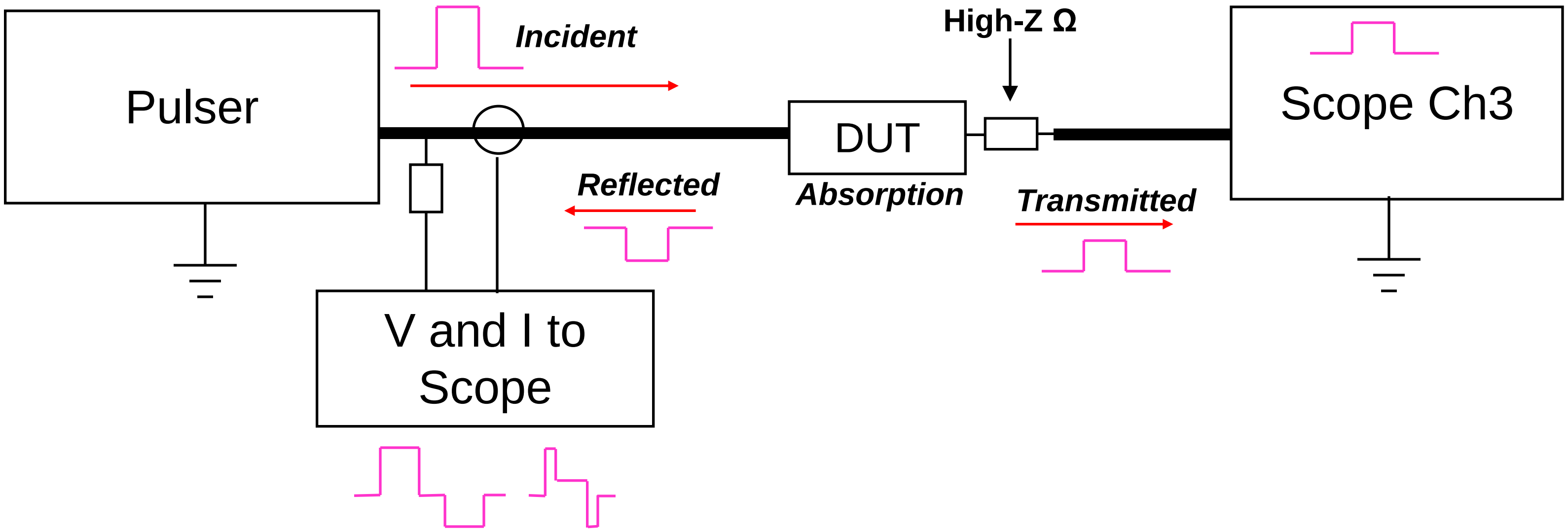
Section 4: TLP Variants

- Time Domain Reflection and Transmission (TDR-T)
  - DUT in series with pulse transmission path
  - 100Ω Impedance



Section 4: TLP Variants

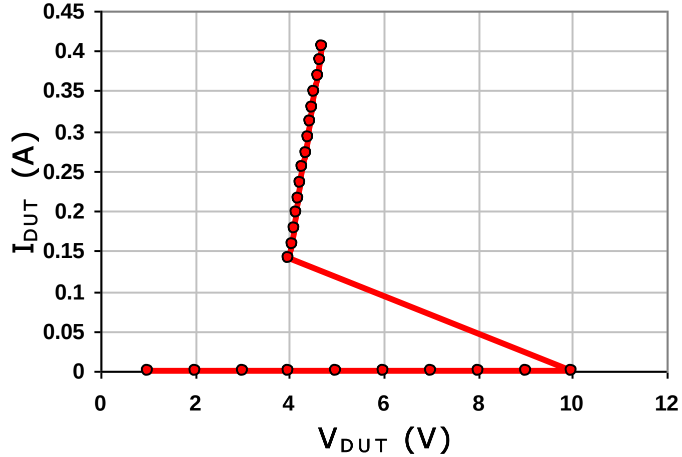
- High-Z Time Domain Reflection and Transmission (TDR-T)
  - DUT in series with pulse transmission path
  - 500Ω, 1kΩ Impedance



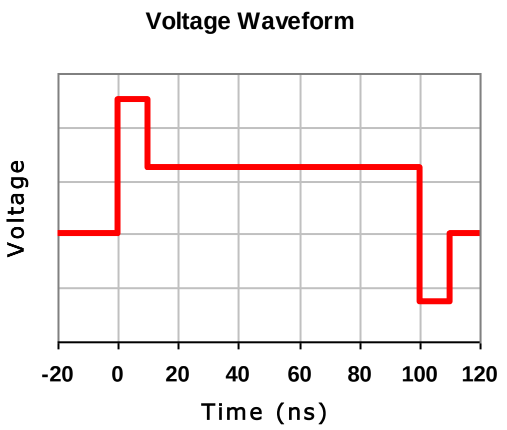
Interpreting TLP Data

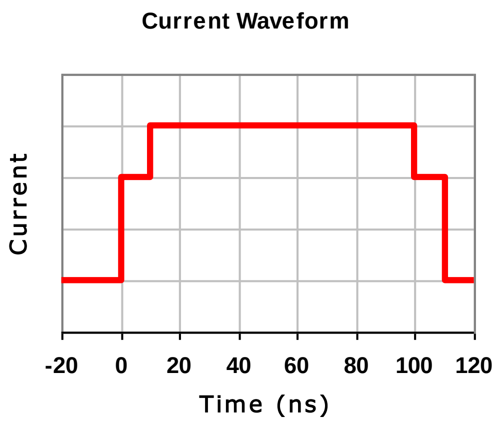
Section 5: Interpreting TLP I/V Curves

- What information do TLP I/V Curves provide?



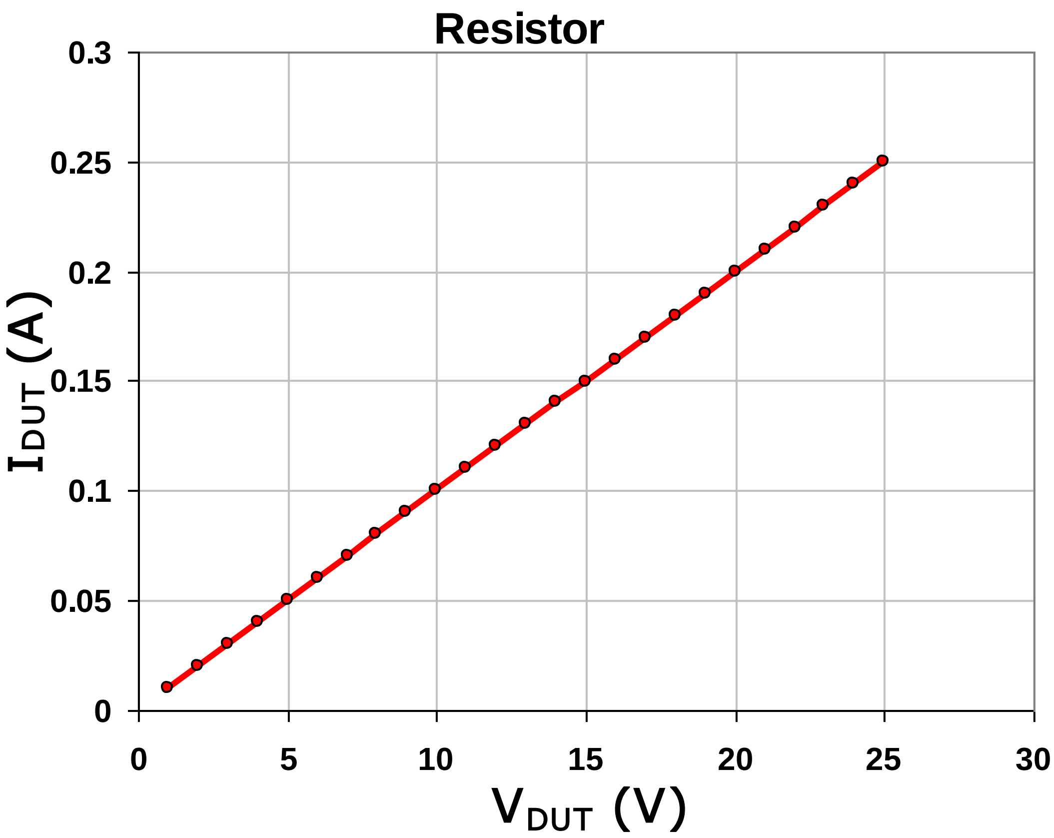
- What information do TLP waveforms provide





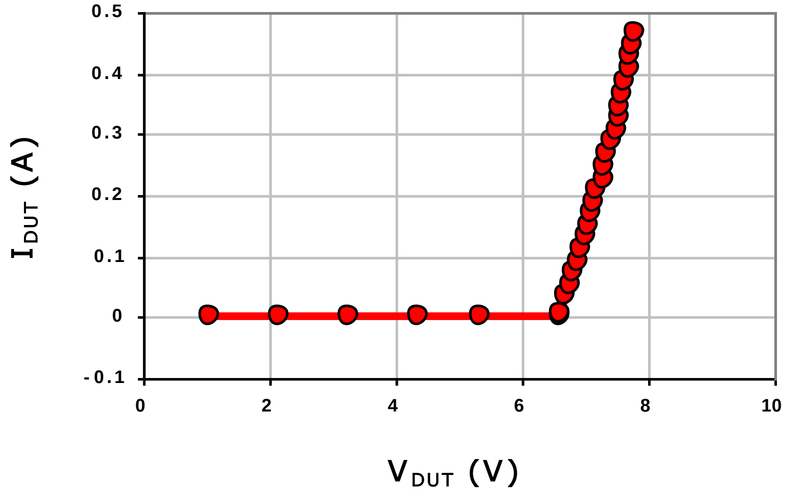
Section 5: Interpreting TLP I/V Curves

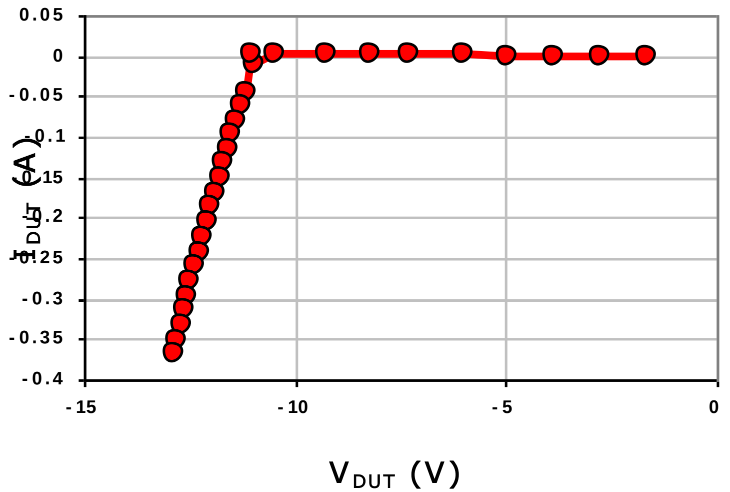
- Device: Resistor
  - Ω is constant no matter wha
    voltage is applied



Section 5: Interpreting TLP I/V Curves

- Device: Zener Diode
  - Turn-on Voltage
  - Breakdown Voltage

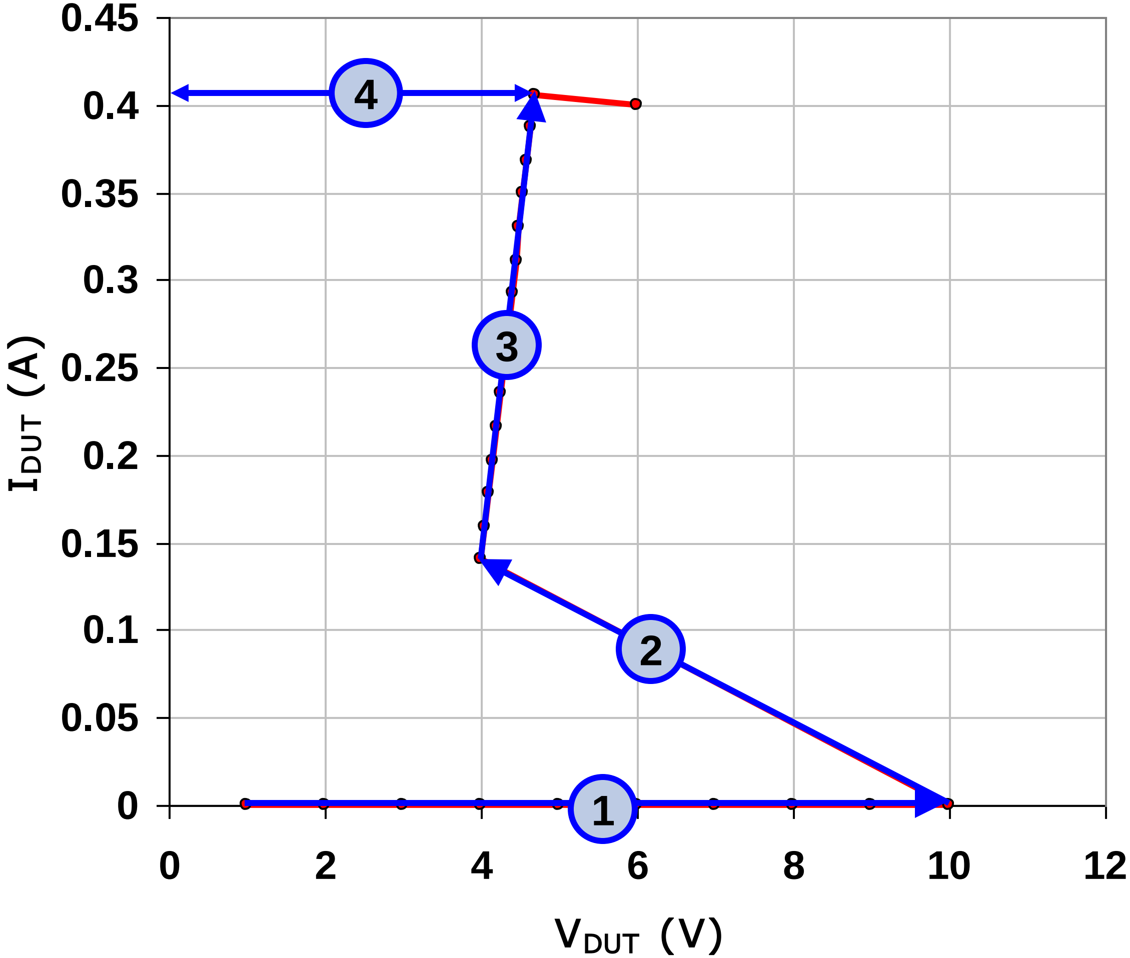




Section 5: Interpreting TLP I/V Curves

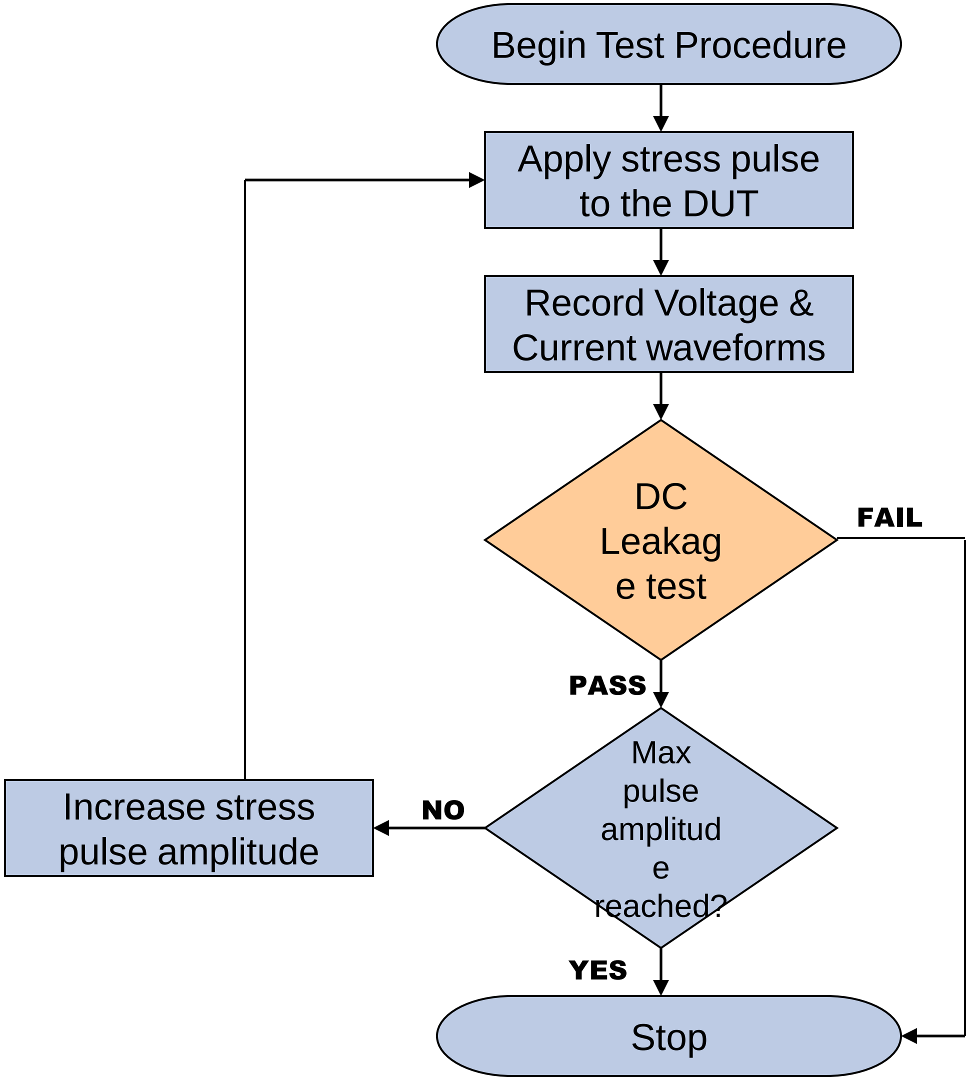
- Device: Snapback Protection Structure

1. Low Voltage TLP Pulses
   - Open Circuit
2. Snapback Threshold
   - Begins conducting current
3. On Resistance
4. Failure Level
   - Peak Current



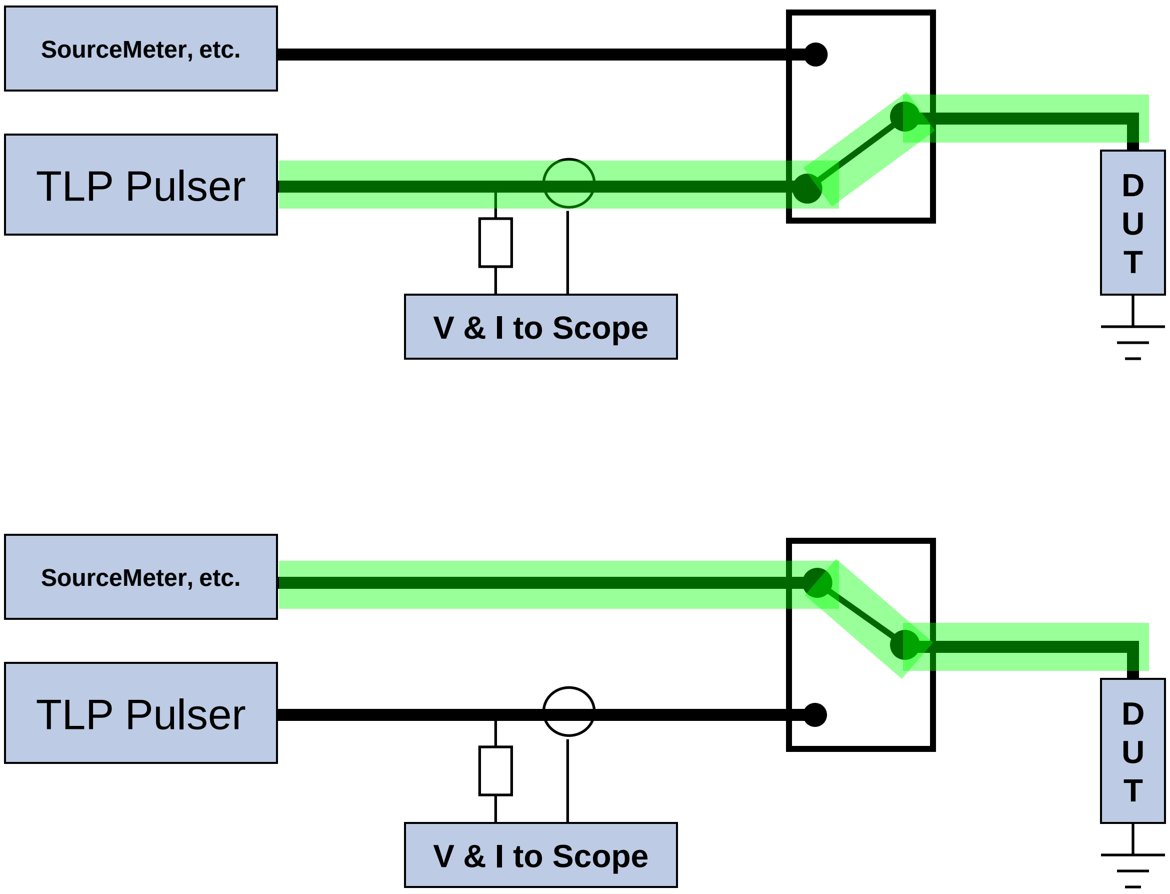
Section 5: Interpreting TLP Data

- How is failure detected?
  - DC leakage test after each TLP pulse



Section 5: Interpreting TLP Data

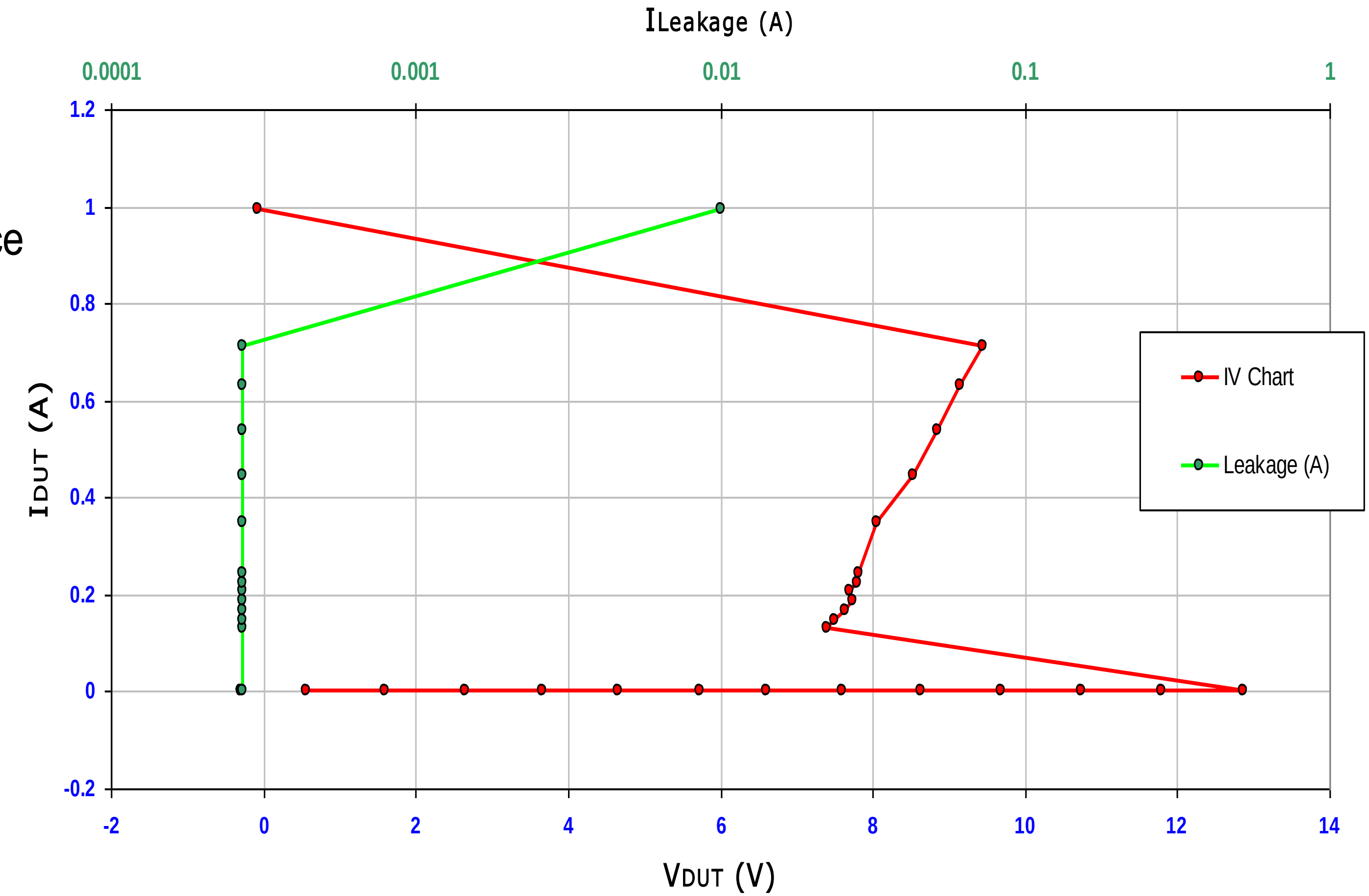
- How is failure detected?



Section 5: Interpreting TLP Data

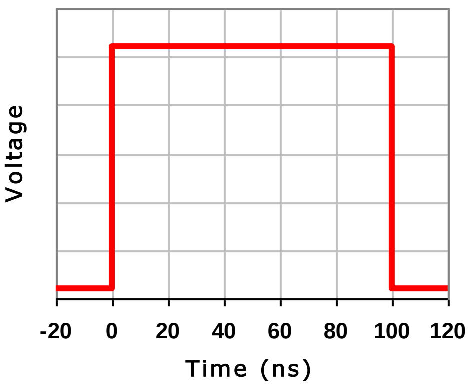
- How is failure detected?

- DC Leak Test
  - Force 14V
  - 10mA Compliance
  - >9mA Failure



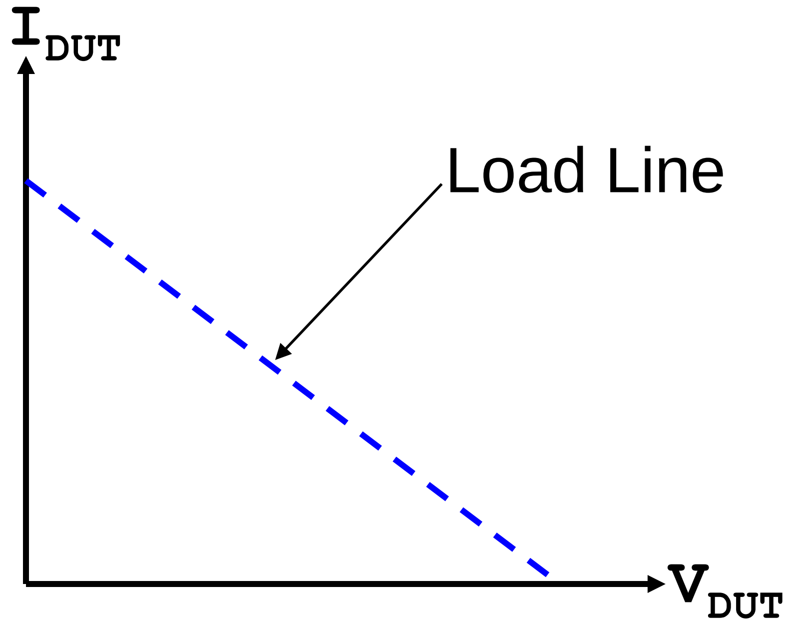
Section 5: Load Lines

- Precise amount of energy under curve
- Controlled impedance circuit
- Conservation of energy



- **Pulsed = V_{DUT} + (I_{DUT} * Z_{TLP})**

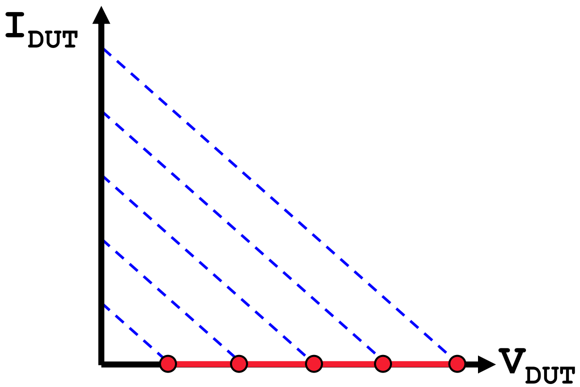
- *For a given TLP Amplitude, the measured V and I will always reside on that Amplitude's Load Line*



Section 5: Load Lines

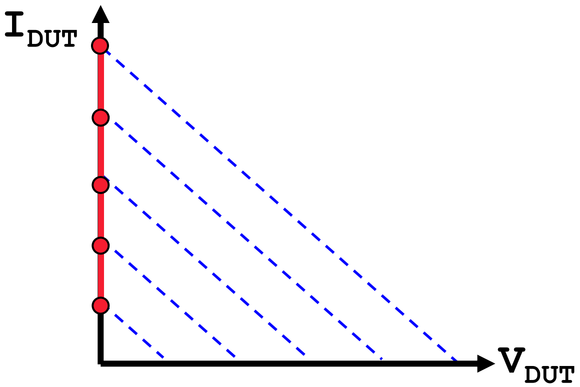
- Open Circuit:

V_{Pulse}	V_{DUT}	I_{DUT}
50	50	0
100	100	0
150	150	0
200	200	0
250	250	0



- Short Circuit:

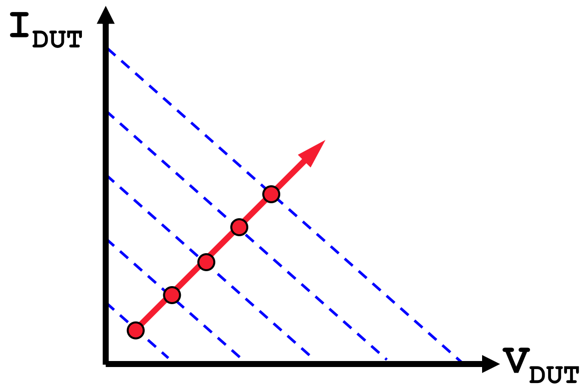
V_{Pulse}	V_{DUT}	I_{DUT}
50	0	1
100	0	2
150	0	3
200	0	4
250	0	5



Section 5: Load Lines

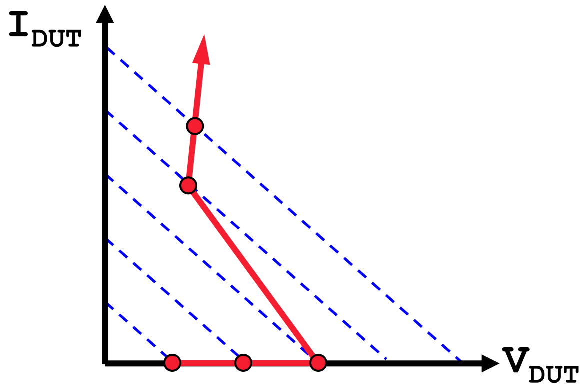
- 50Ω Circuit:

V_{Pulse}	V_{DUT}	I_{DUT}
50	25	0.5
100	50	1
150	75	1.5
200	100	2
250	125	2.5



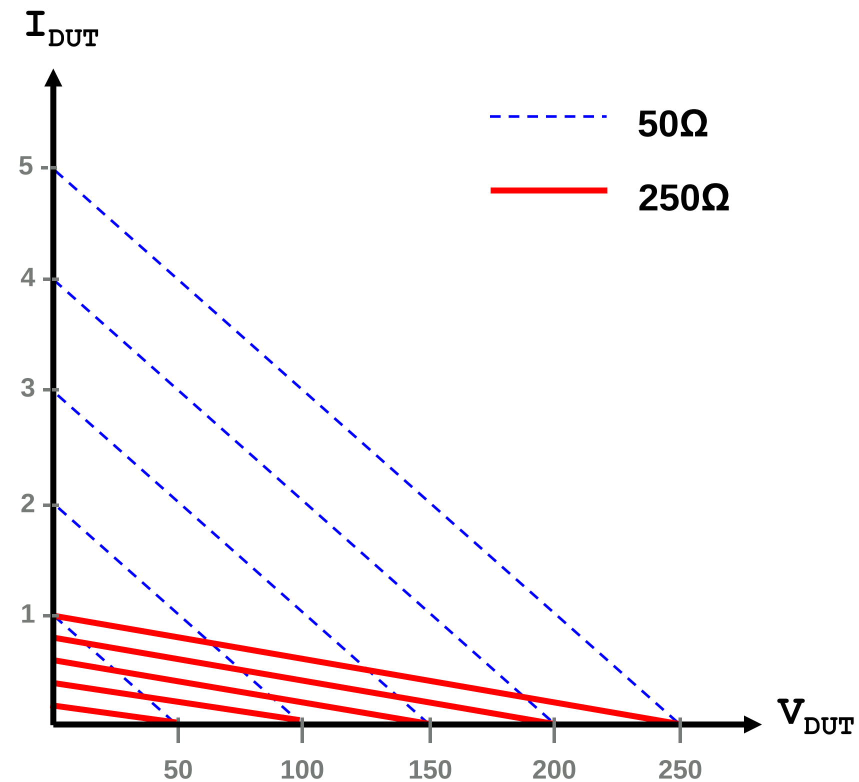
- Snapback Device:

V_{Pulse}	V_{DUT}	I_{DUT}
50	50	0
100	100	0
150	150	0
200	60	2.8
250	70	3.6



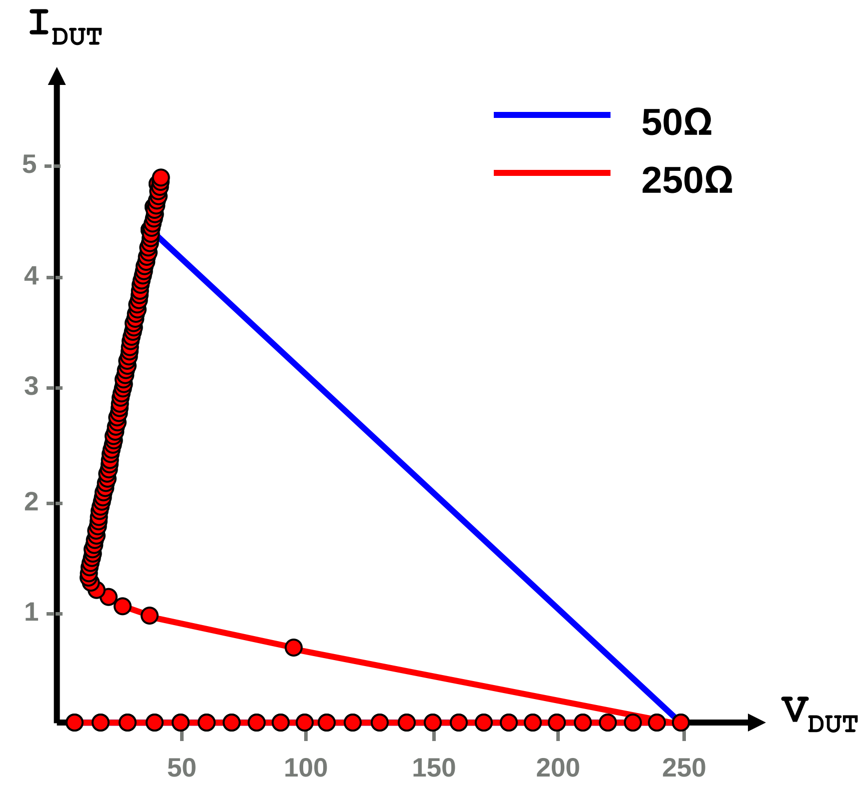
Section 5: Load Lines and System Impedance

- How does system impedance affect the Load Line?
  - Low Impedance
    - More current flow for a given voltage
  - High Impedance
    - Less current flow for a given voltage
  - $V_{Pulse} = V_{DUT} + (I_{DUT} * Z_{TLP})$
  - $I_{DUT} = (V_{Pulse} - V_{DUT}) / Z_{TLP}$



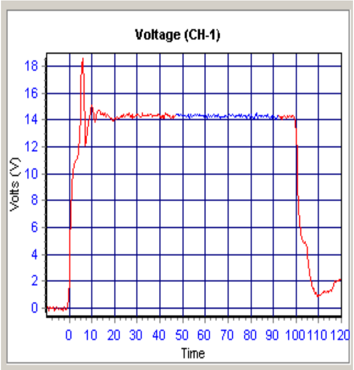
Section 5: System Impedance

- Why would I want to change the system impedance?
  - Snapback device recap:
    - Voltage triggered
    - Fails by peak current
  - What if Snapback device has high trigger voltage, low peak current?
    - 250V Trigger Voltage
    - 5A peak current

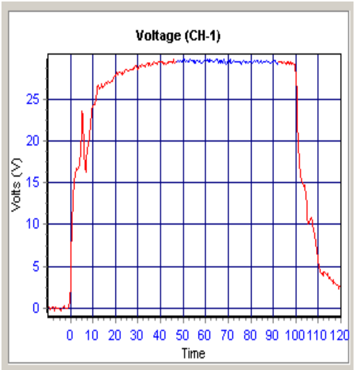


Section 5: System Impedance

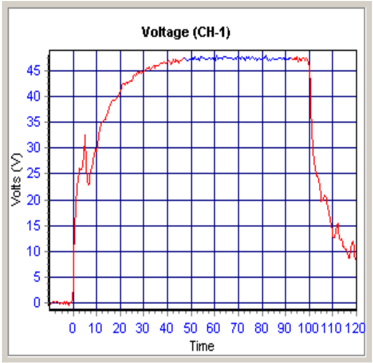
- Characteristics of High Impedance



50 Ω



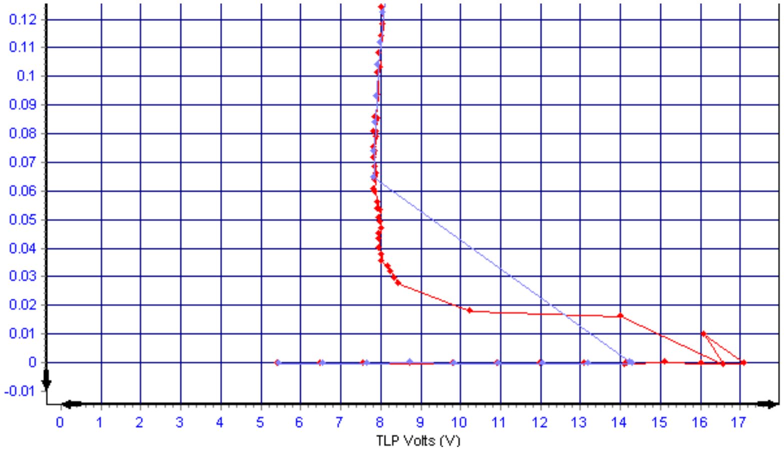
500 Ω



1000 Ω

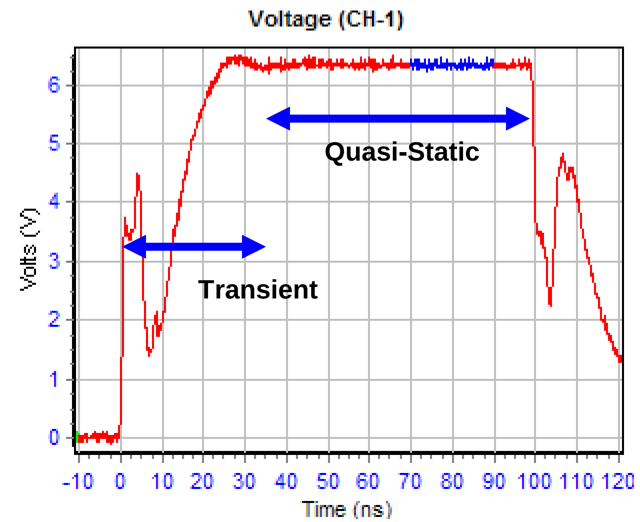
- Longer settling time
  - Time Constant = $\mathbf{Z_{TLP}}$ * $\mathbf{C_{DUT}}$

- Unstable turn-on region
  - Enough Voltage to turn-on
  - Not enough Current to remain on

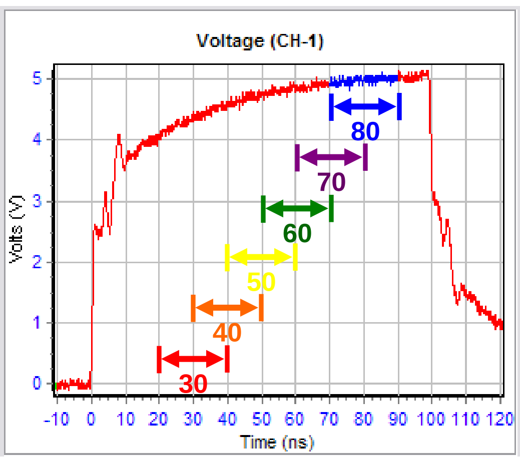


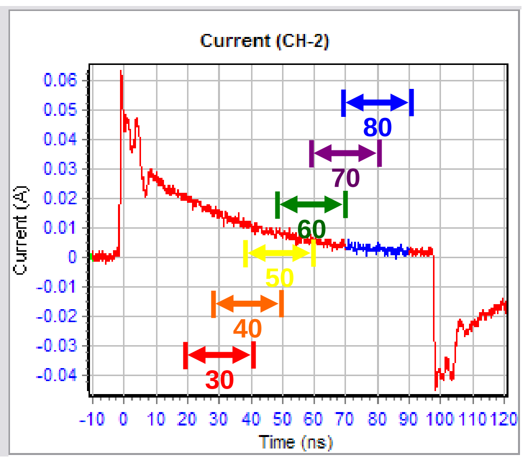
Section 5: Quasi-Static Region

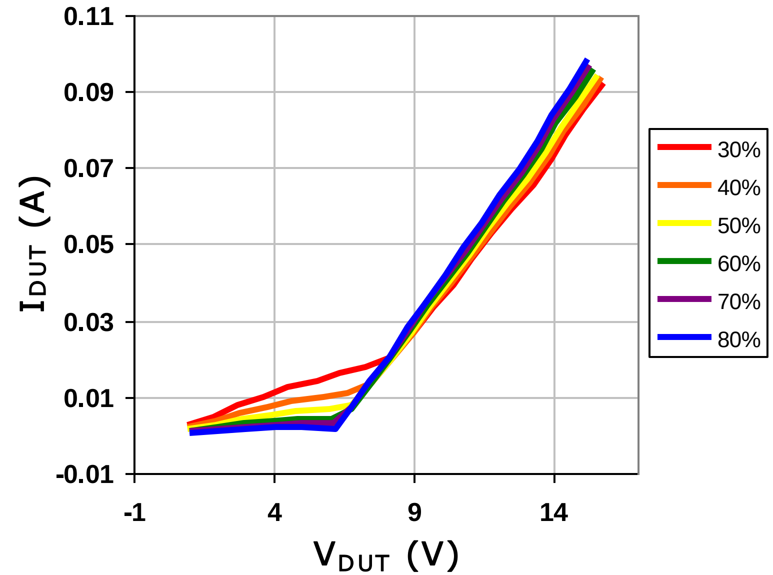
- What defines the "quasi-static" region?
  - After transient response has settled



- What if the device never settles?

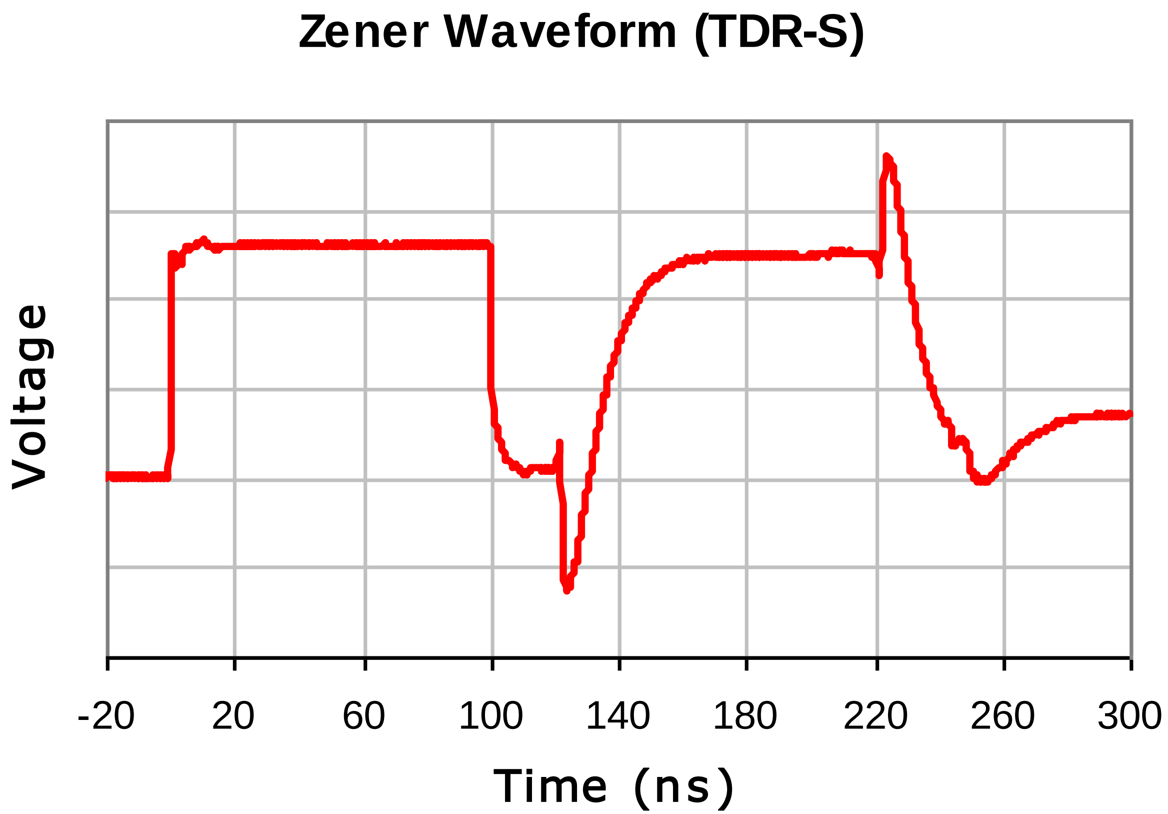






Section 5: Transient Region

- Does the transient response tell me anything?
  - Turn-on time
  - Capacitance



TLP Accuracy

- Understand limitations
- Optimize measurements

Section 6: TLP Accuracy

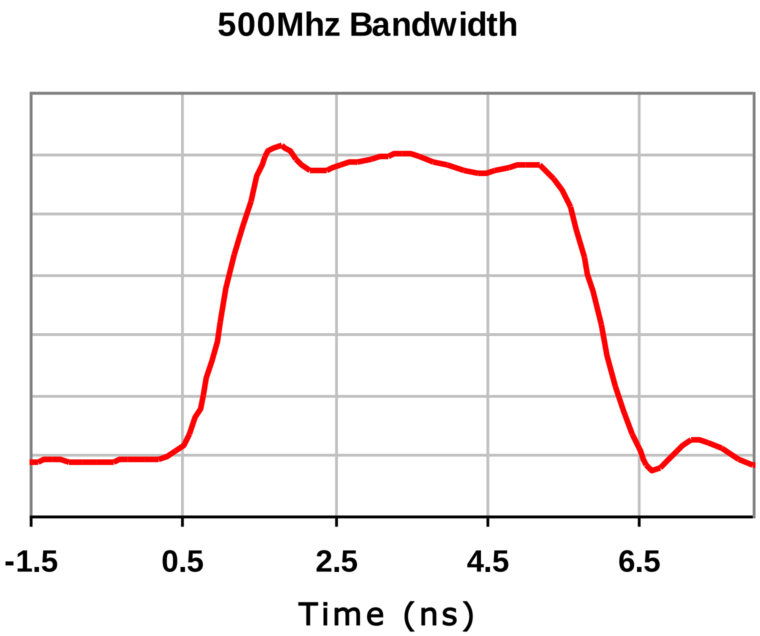
- Misconception: **TLP** is as precise as **DC curve tracing**

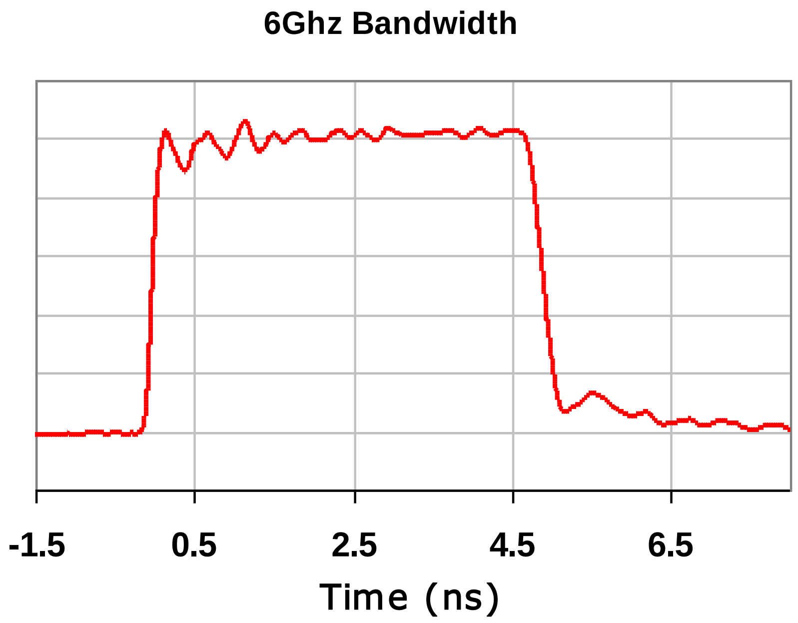
- What affects the accuracy of **TLP** measurements?
  - Short duration means smaller sample size
  - Measurement instrument limitations
  - Parasitics and noise
  - Contact resistance

- How are these limitations addressed?

Section 6: TLP Accuracy – How Are Limitations Addressed?

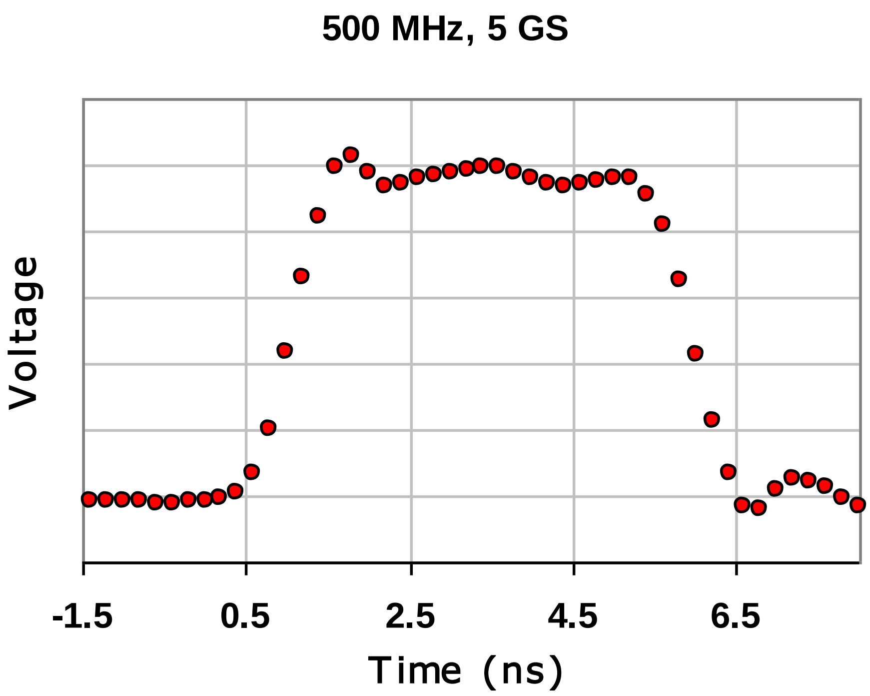
- Oscilloscope: Bandwidth

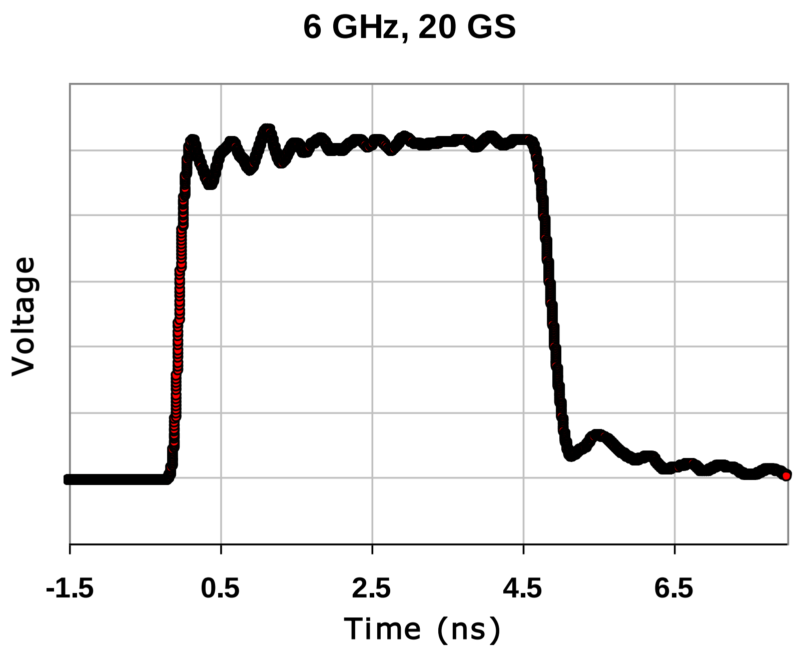




Section 6: TLP Accuracy – How Are Limitations Addressed?

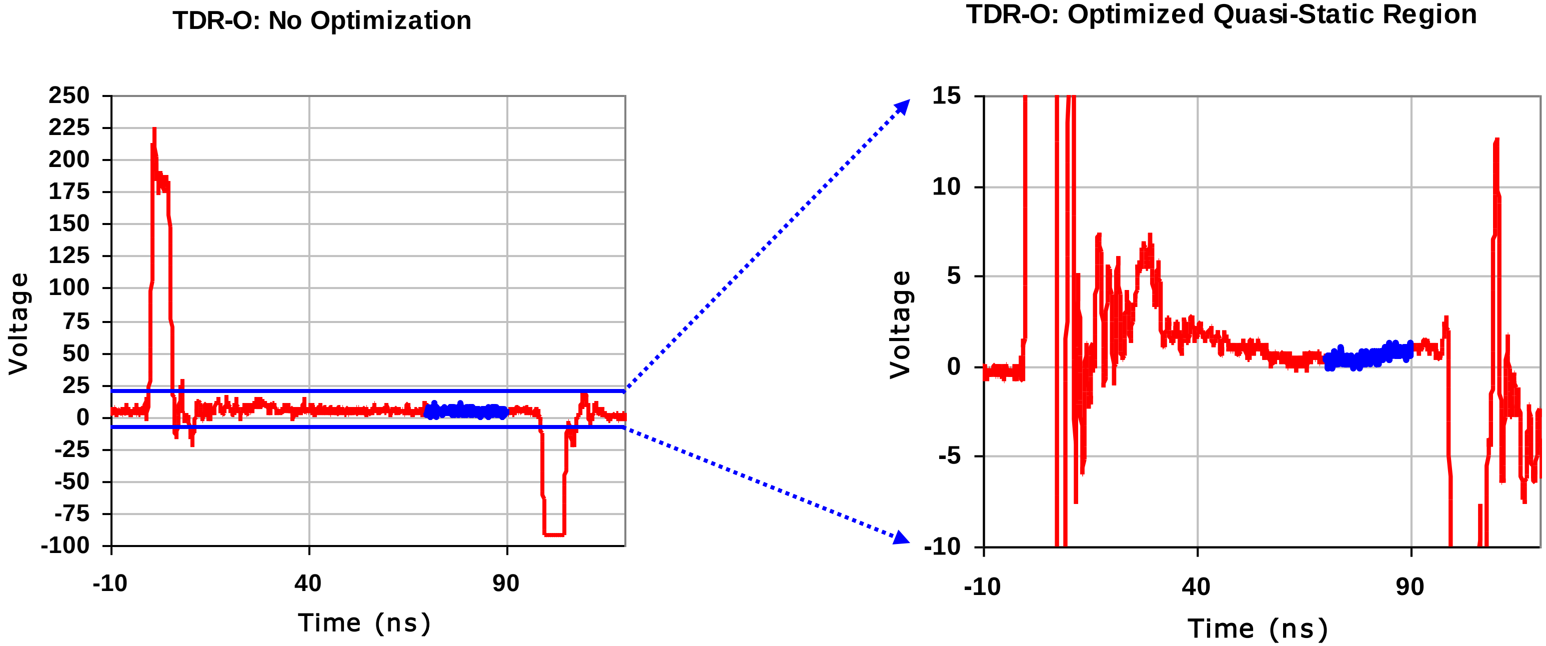
- Oscilloscope: Sampling rate





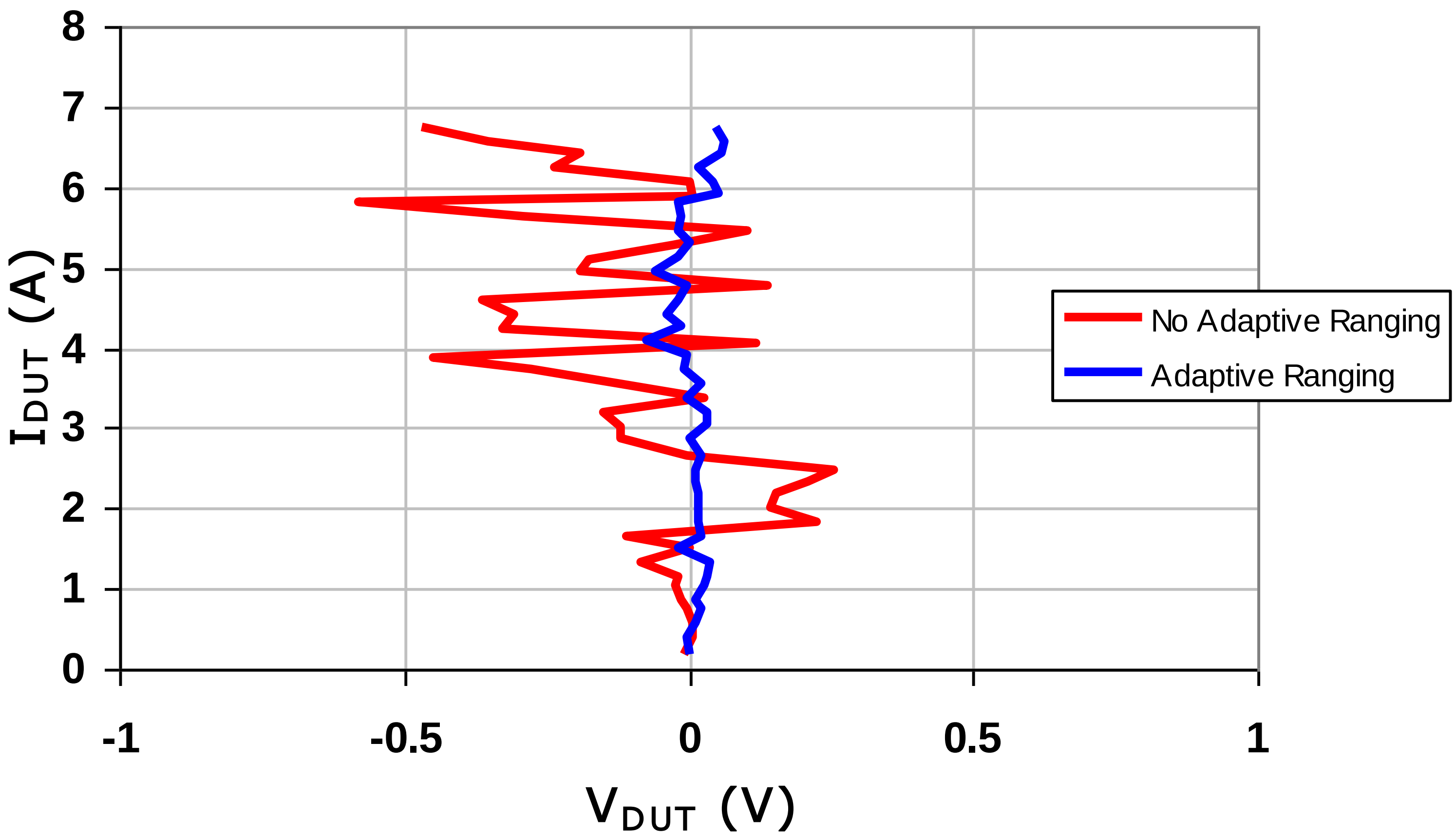
Section 6: TLP Accuracy – How Are Limitations Addressed?

- Oscilloscope: Signal digitization optimization
  - 8 bits of resolution = 256 possible levels



Section 6: TLP Accuracy – How Are Limitations Addressed?

- Oscilloscope: Signal digitization optimization



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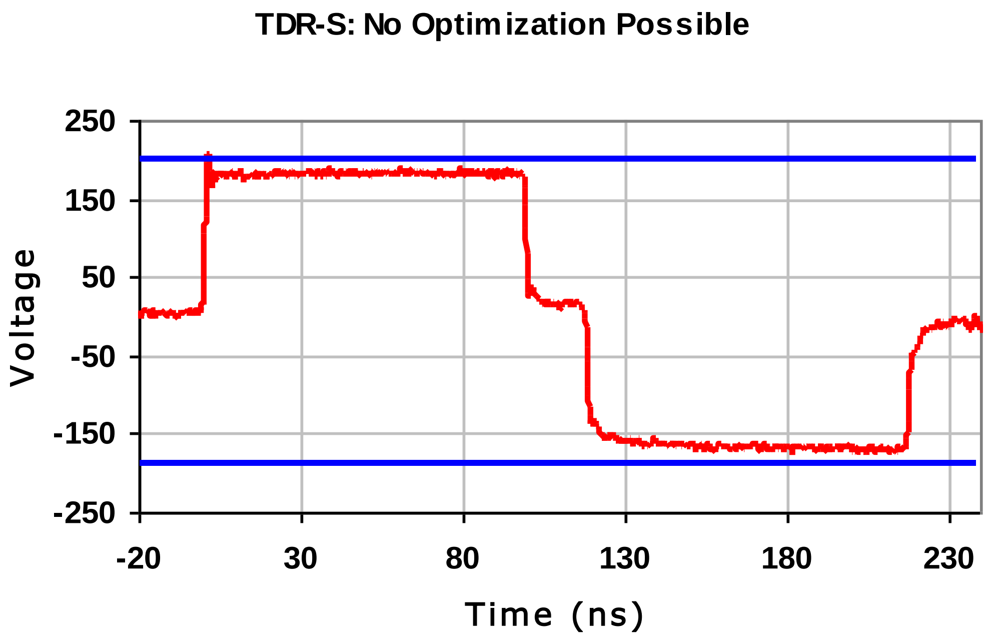
Section 6: TLP Accuracy – How Are Limitations Addressed?

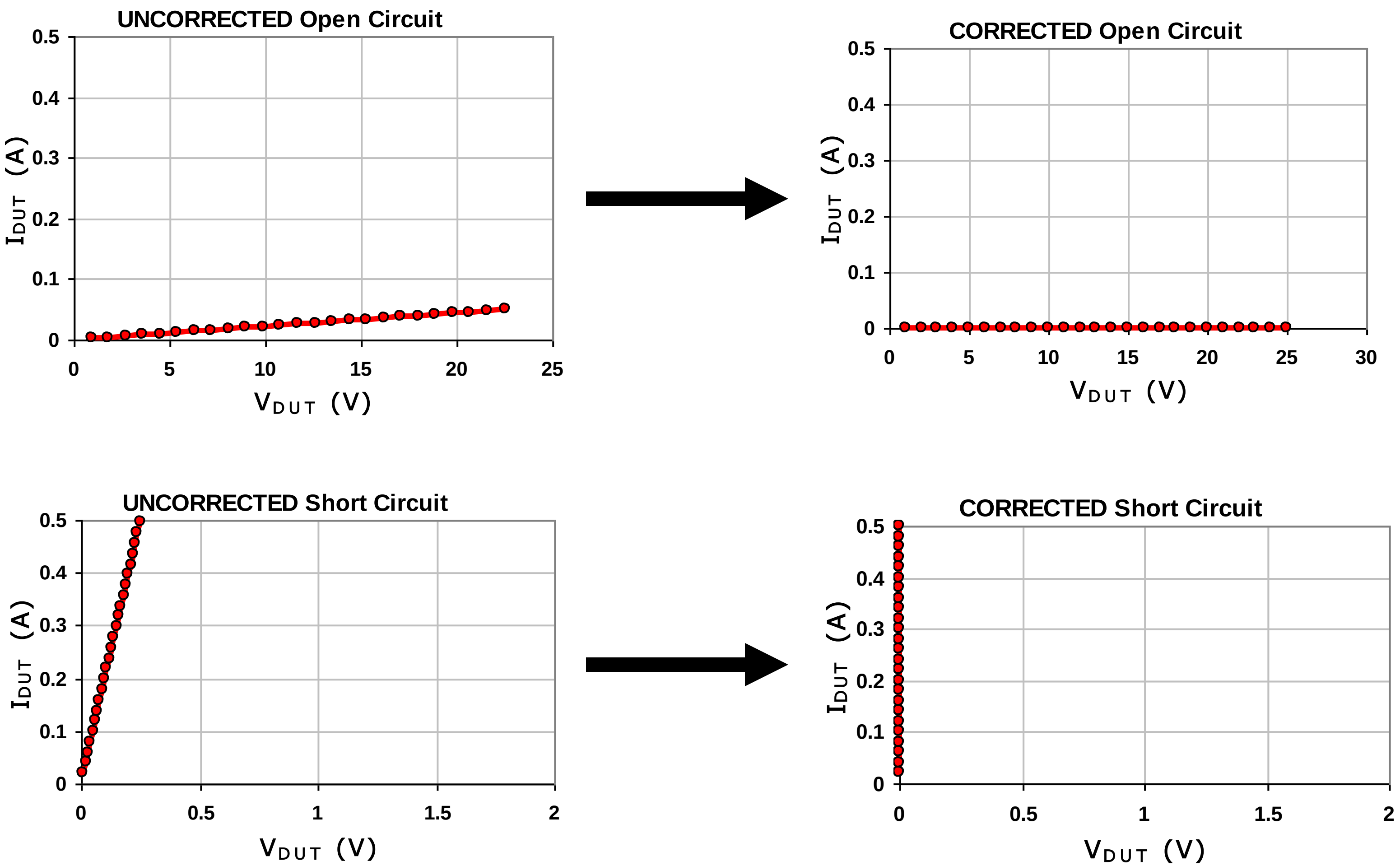
- Oscilloscope: Signal digitization optimization



- Overlapped waveform advantageous for best resolution

Section 6: TLP Accuracy – How Are Limitations Addressed?

- Parasitics:
  - Factor out from DUT measurement



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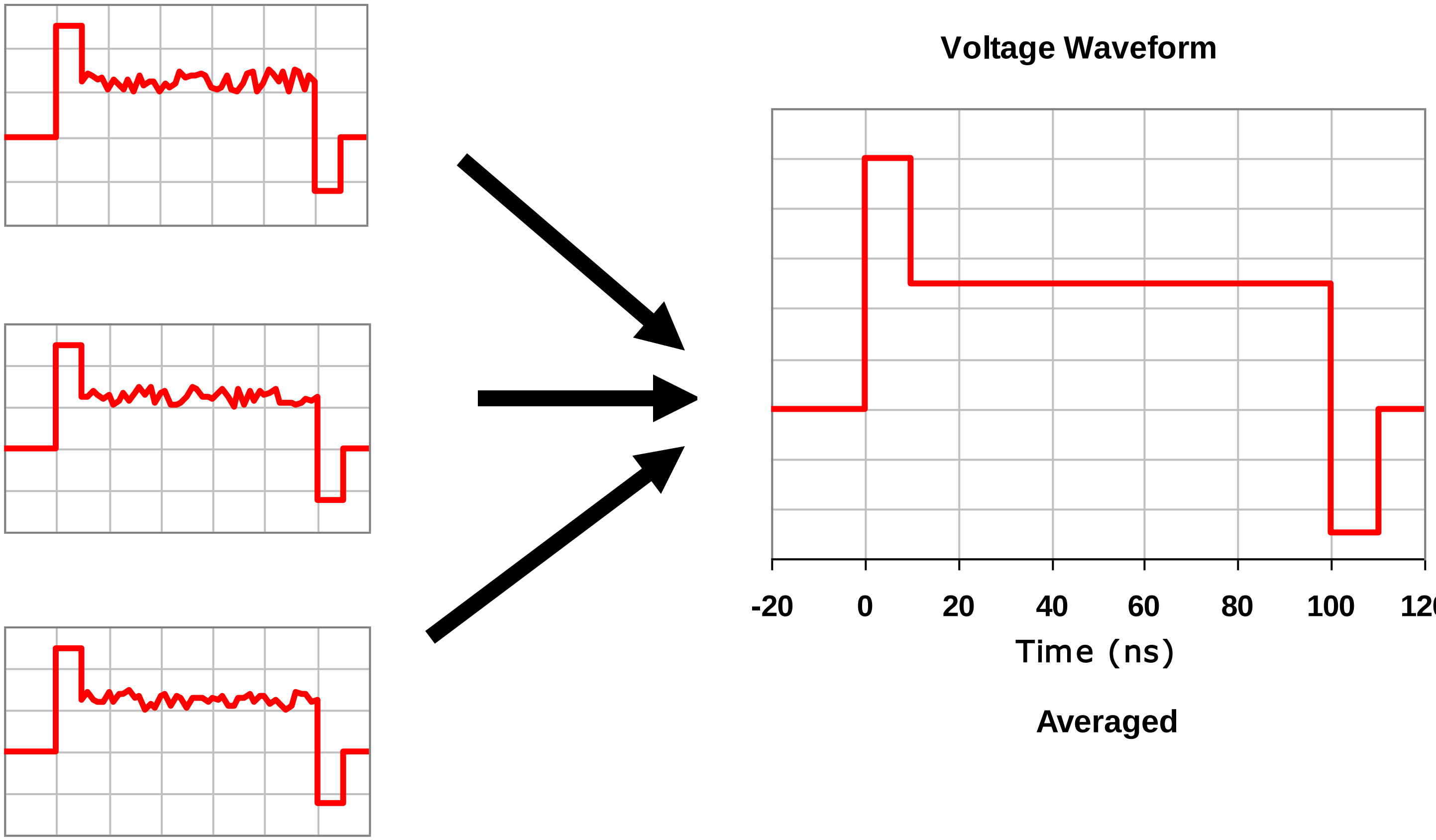
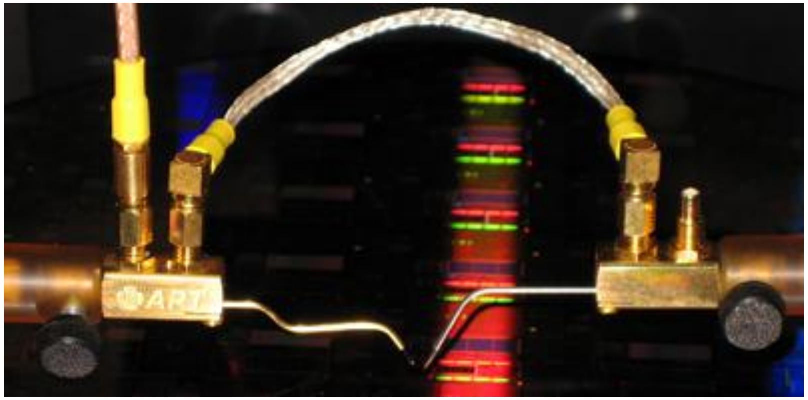
Section 6: TLP Accuracy – How Are Limitations Addressed?

- Noise:
  - Multiple pulses

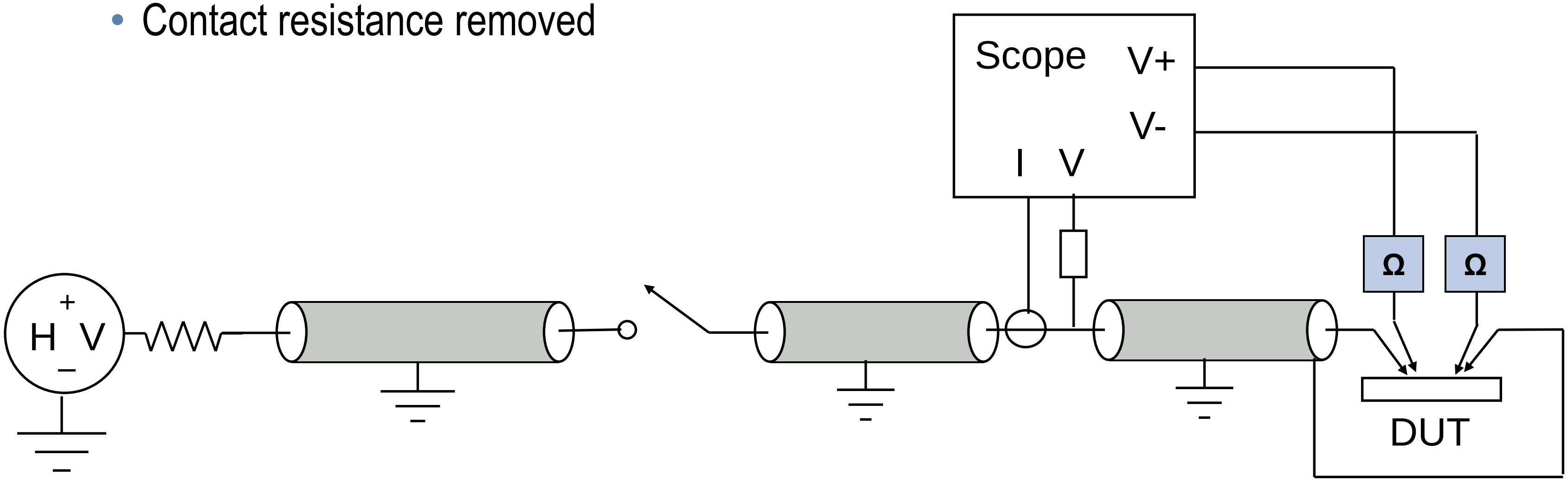


Section 6: TLP Accuracy – How Are Limitations Addressed?

- Contact Resistance
  - Changes on each touchdown



  - 4-point TLP (Kelvin)
    - Contact resistance removed

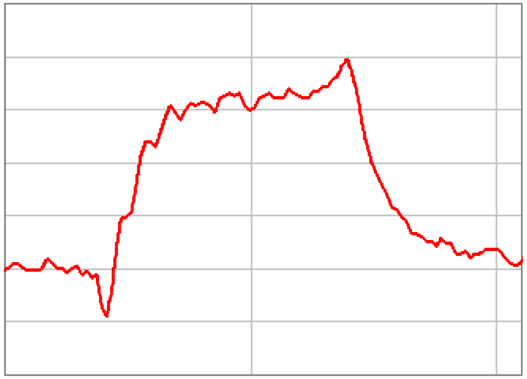


VF-TLP

- Similarities and differences
- Additional requirements

Section 7: VF-TLP

- What makes VF-TLP different?
  - Short pulse width
    - 1ns – 10ns
  - Fast rise time
    - 100ps – 200ps
  - Transient response emphasized



  - Mimics CDM event

Section 7: VF-TLP

- Additional requirements for VF-TLP?
  - Oscilloscope bandwidth
    - 200ps rise time = 5 GHz
  - Oscilloscope sampling rate
    - 1ns @ 20GS/sec = 20 samples

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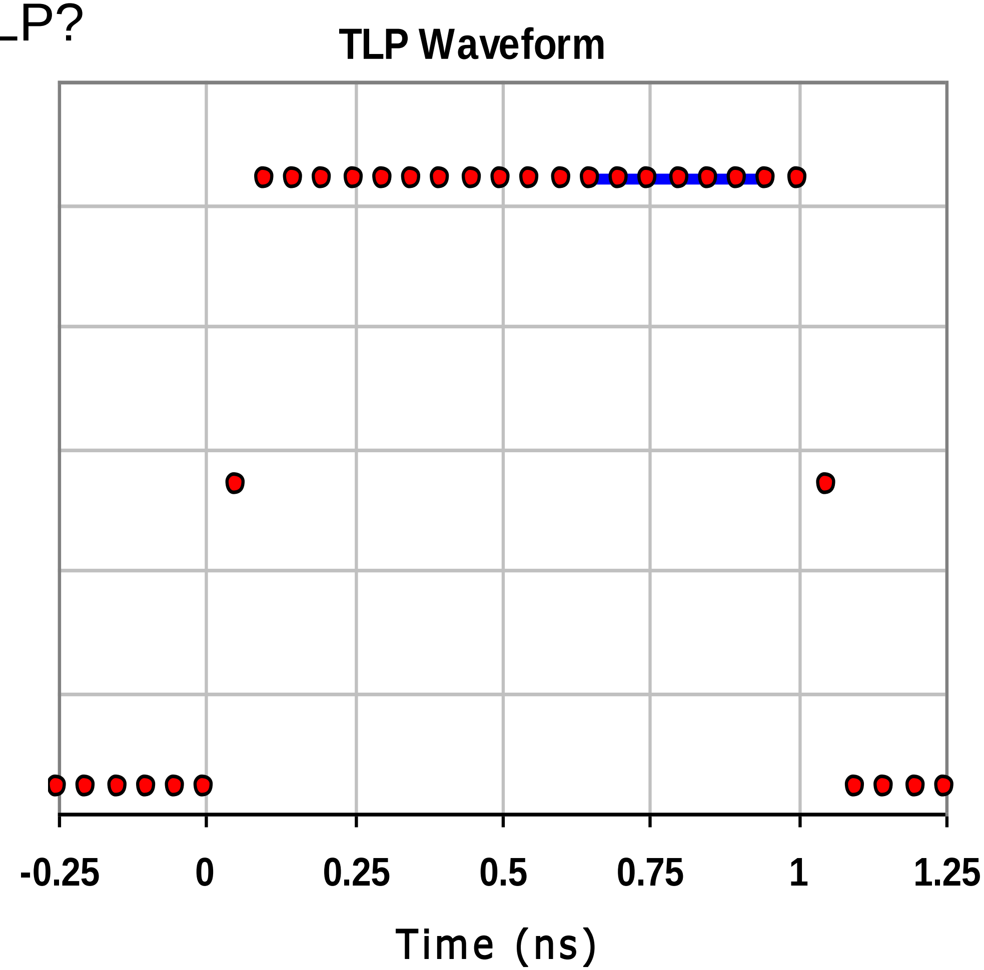
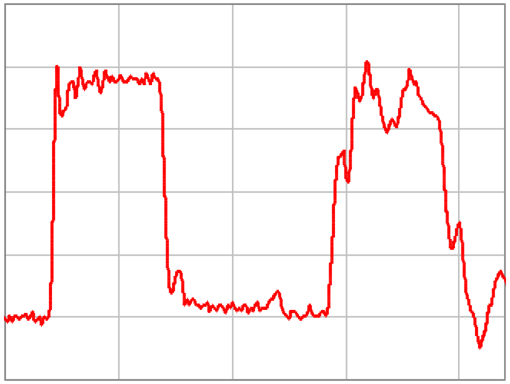
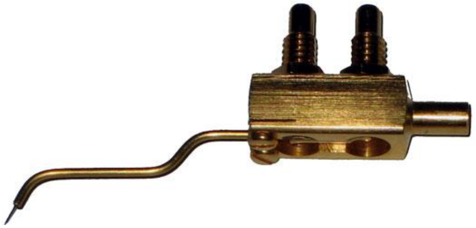


Section 7: VF-TLP

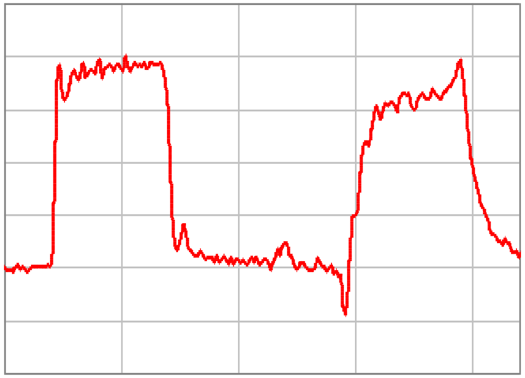
- Additional requirements for VF-TLP?
  - More sensitive to parasitics
  - Wafer-level only
  - RF-rated probes recommended

Package Level

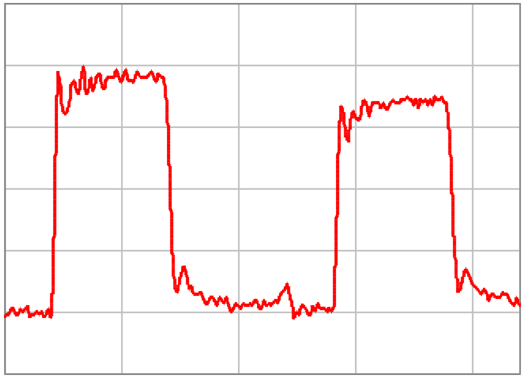




Coax Wafer Probe - 4 GHz

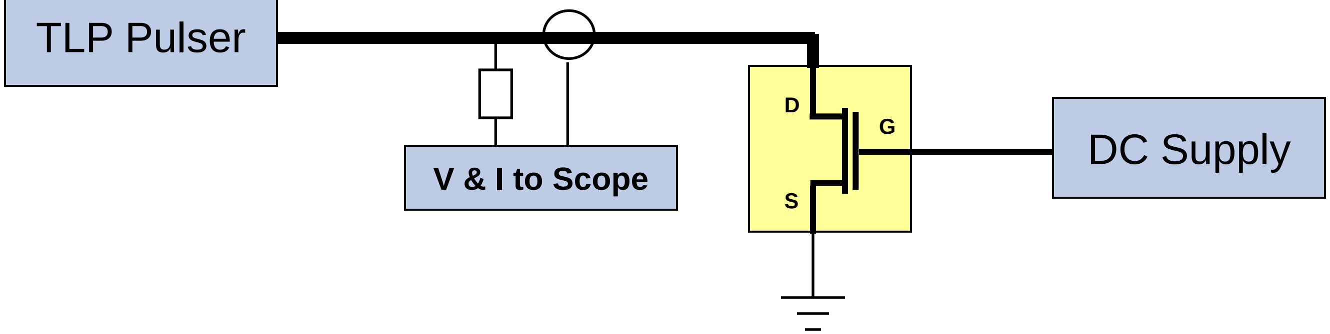


RF Wafer Probe - 40 GHz



Additional Topics

- How do I power up my device during TLP?
  - DC BIAS supplies can be added



Additional Topics

- Does TLP correlate to HBM?
- Does VF-TLP correlate to CDM?
- Why use TLP instead of a TDR machine, or solid state pulse generator?
- TLP Circuit is a closed system, will reflections continue indefinitely?