10µs pulse test solution for VCSELs a key component of modern LiDAR and 3D sensing systems

김수길 부장
David Kim

KEITHLEY
A Tektronix Company

3D Sensing Market

VCSEL-BASED GROWTH

Time of Flight (LiDAR)

Measures time of signal bounce back

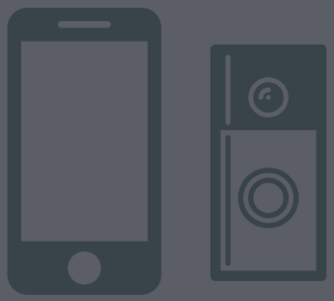
Structured Light

Projects infrared patterns and captures warping

Stereoscopic Imaging

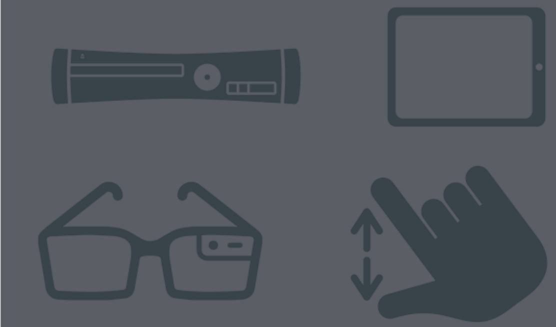
3D Triangulation through Multiple Cameras

LiDAR Application



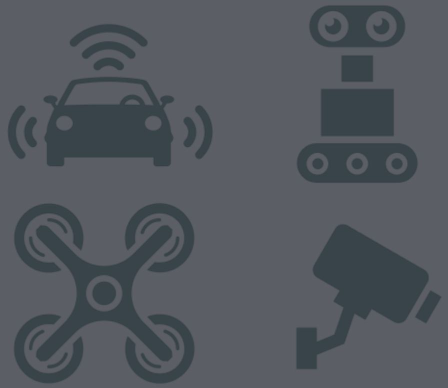
SHORT DISTANCE
(Facial recognition and security)

Phones
Smart Doorbells



MID DISTANCE
(Gesture recognition & augmented reality)

Home Appliances
Tablets
Smart Glasses/Headsets
Gaming Systems



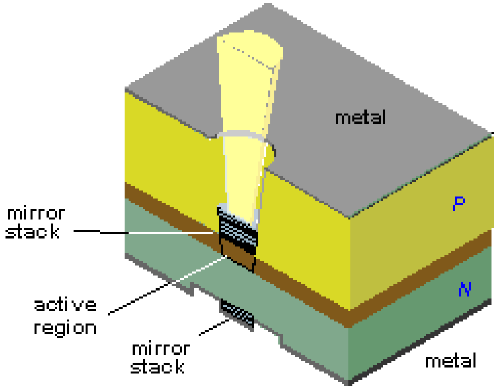
LONG DISTANCE
(Navigation and Mapping)

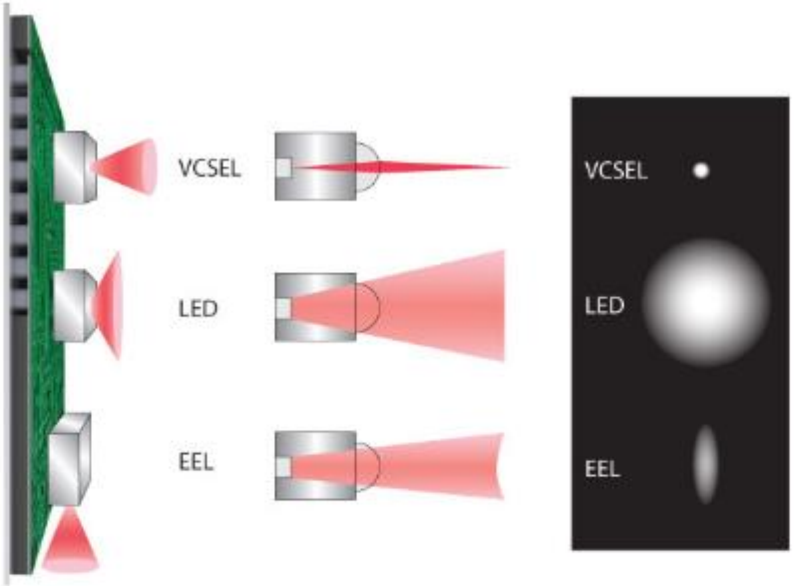
Autonomous Vehicles
Robotics
Drones
Security

Why is VCSEL for 3D application

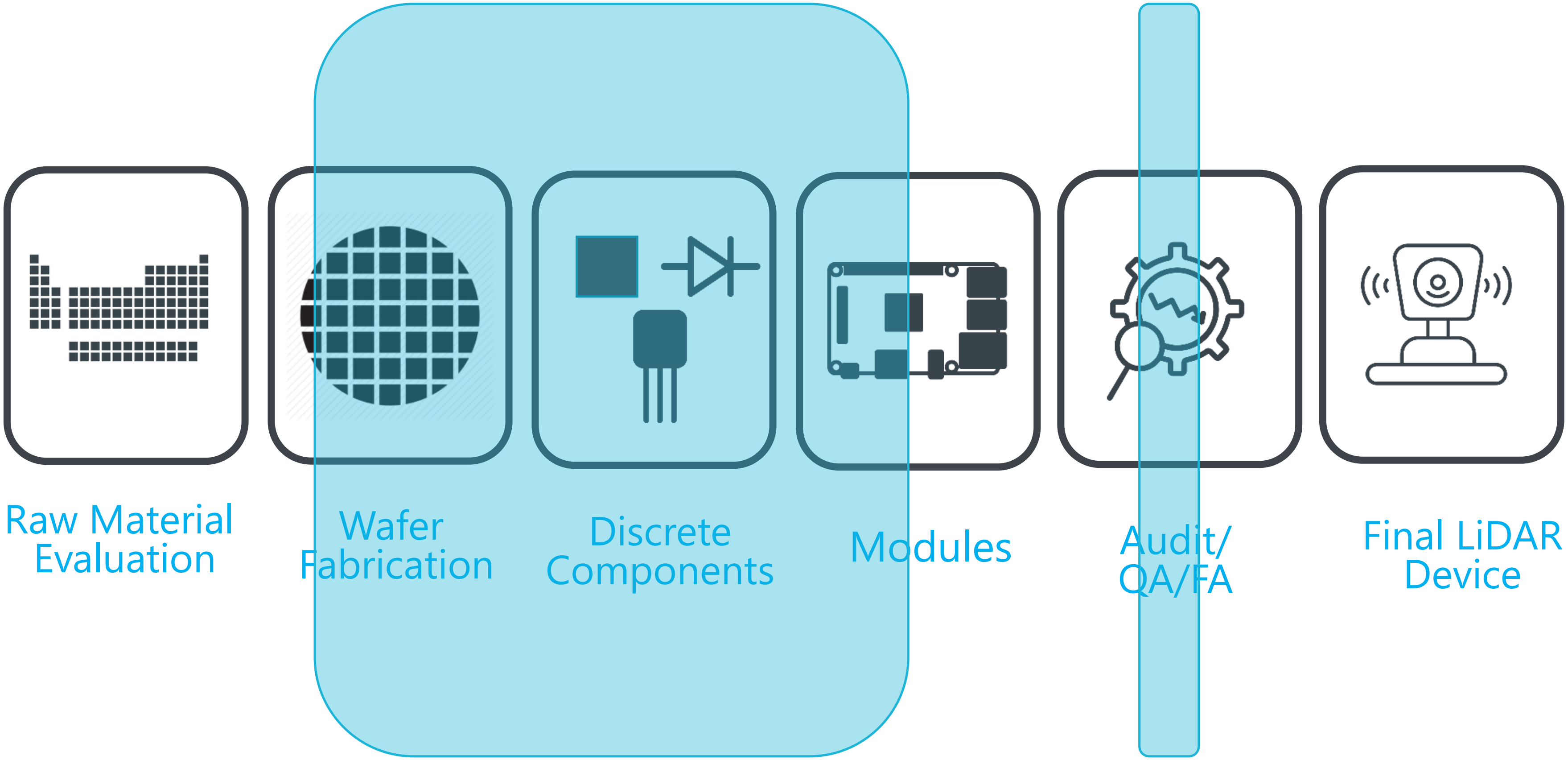
Advantages of VCSELs

- Surface vs Edge – Manufacturing Yield/test
- Integratability – compatibility detectors
- Scalability – 2D array’s (1-D only for EEL)
- Wavelength Stability (Temperature)
- Higher Beam Quality
- Reliability
- Testability





VCSEL Workflow



Raw Material Evaluation

Wafer Fabrication

Discrete Components

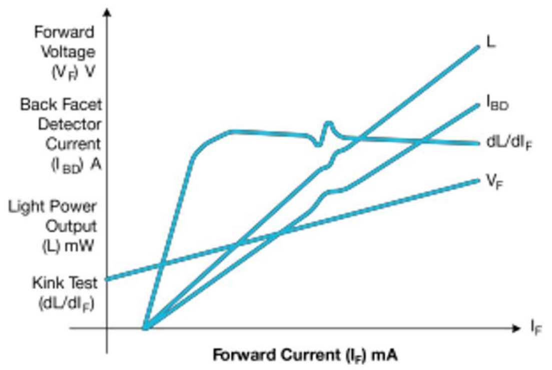
Modules

Audit/ QA/FA

Final LiDAR Device

VCSEL LIV Test Setup

LIV Measurement

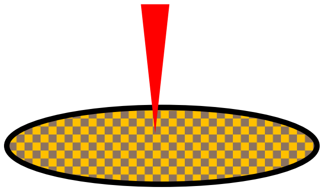


SMU and DMM

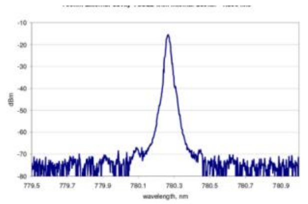
Photo diode

Integration Sphere

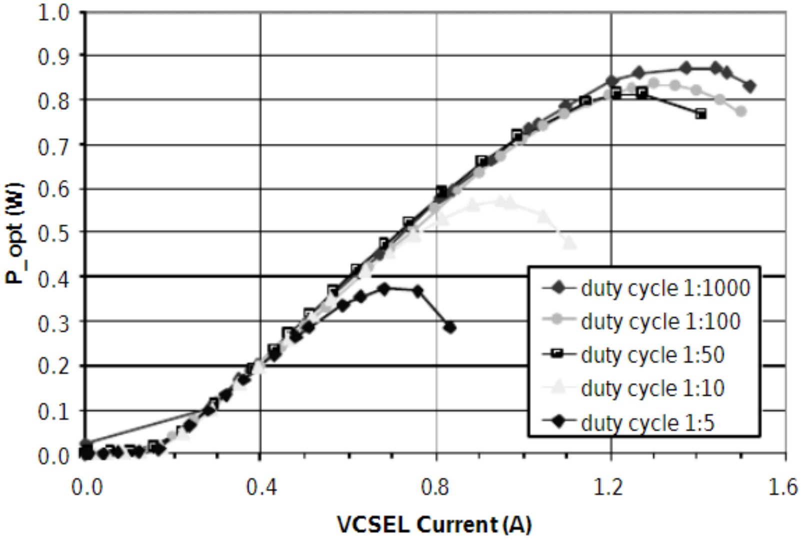
VCSEL Wafer

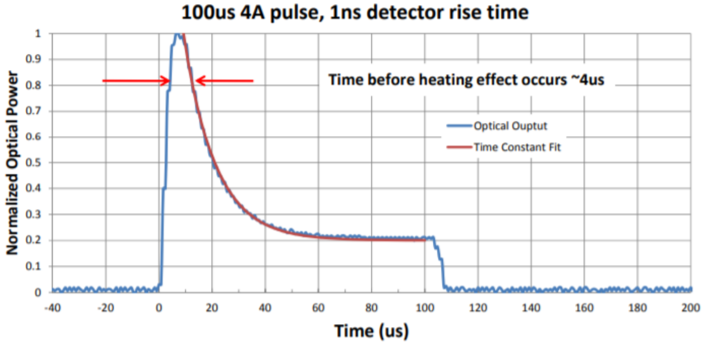


Optic Measurement



Why Short Pulse is Required



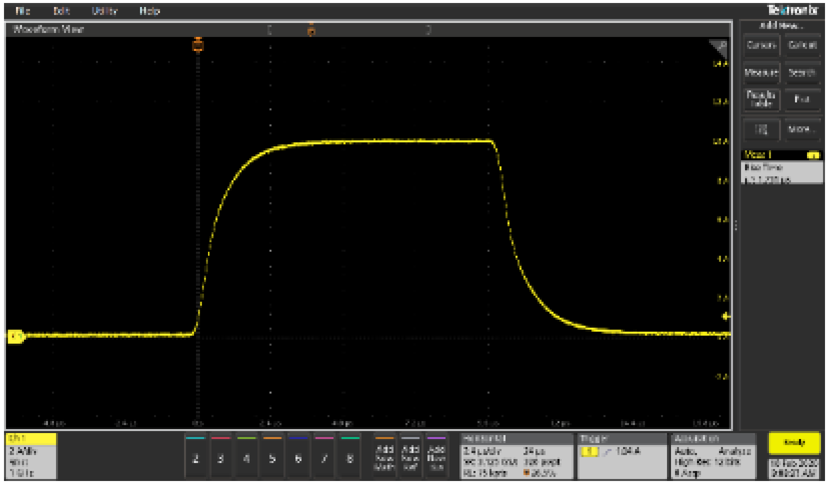


Temporal response of the optical power to a 100us electrical pulse (blue) and the fit thermal time constant (red)

- Self-heating in higher duty cycle
- Peak Power is limited by heating
- Higher peak power operation can be obtained when driving the laser with short electrical pulses that are significantly shorter than the thermal time constant of the VCSEL
- ref - the left graph is referred to a paper of Philips Photonics
- ref - the right graph is referred to Finisar application note AN-2109

Introducing the 2601B-PULSE System SourceMeter® 10 µsec Pulser/SMU Instrument

SUPERIOR CURRENT PULSE OUTPUT PERFORMANCE



Industry Leading Performance

1. 10 A @ 10 V at 10 µs pulse
2. DC capability up to ±40 V @ ±1.0 A, 40 Watt
3. No tuning required for inductive loads up to 3 µH. Remote test head not required
4. Dual 1 Msample/sec digitizers for high speed I/V pulse measurements (**Pulser function only, not SMU**)
5. TSP® (Test Script Processing) technology embeds complete test programs inside the instrument for best-in-class system-level throughput

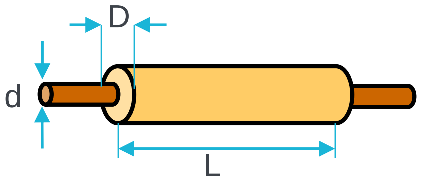
Challenges for Obtaining Short, Fast Current Pulses

- Reducing pulse width requires reducing rise, fall and settling times, which drives need for increased operating bandwidth.

- Pulse quality is affected by total inductance and resistance in the test circuit including the DUT, cables, switches etc.
    - Can cause ringing or oscillation on the rising/falling edges
    - Can increase rise and fall times
- Some solutions require the user to tune the output response of the current source in order to obtain good pulses for a given DUT impedance. Different impedances require different tuning.

Coaxial Cable Inductance

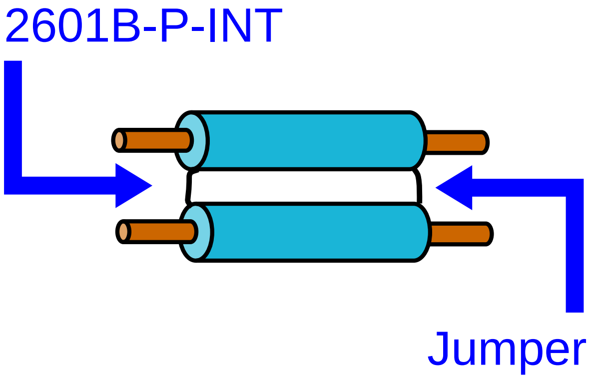
APP NOTE: How to generate 10µs pulse with 2601B-PULSE



$$L = \frac{\mu_0 \mu_r}{2\pi} * \ln\left(\frac{D}{d}\right) * L$$

μ_0 - permeability of free space = $4\ \pi * 10^{-7}$
μ_r - relative permeability typical 1

- Typical BNC Cable
  - D = 3.3mm, d = 1.02mm
  - L is approximately **710nH for 3 meter**



- Recommend short the shields at both ends of the Force HI and LO cables
  - Without shorts, total inductance includes cable inductance plus variable “loop” inductance.
  - Shorting the shields removes the “loop” inductance.
    - Total L of is just 2x that of single cable

Inductance Effects on Short Pulses

Results for 10A pulse from TYPICAL SMU into 0µH,1µH, 3µH and 5µH loads

- Can cause ringing and oscillation
- Inductance affects I-source like capacitance affects V-source
- More inductance, more ringing

- Can increase rise and fall times
- More inductance, longer times

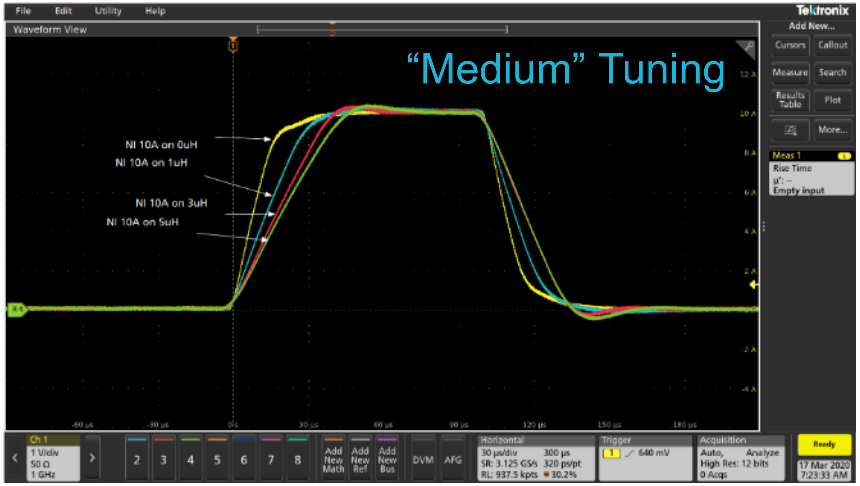
Ref 4
2 A/div
3.125 GS/s
NI_5uH_...

Horizontal
30 µs/div 300 µs
SR: 3.125 GS/s 320 ps/pt
RL: 937.5 kpts 30.2%

Trigger
1 640 mV

Acquisition
Auto, Analyze
High Res: 12 bits
0 Acqs

17 Mar 2020
8:26:26 AM



Ch 1
1 V/div
50 Ω
1 GHz

Horizontal
30 µs/div 300 µs
SR: 3.125 GS/s 320 ps/pt
RL: 937.5 kpts 30.2%

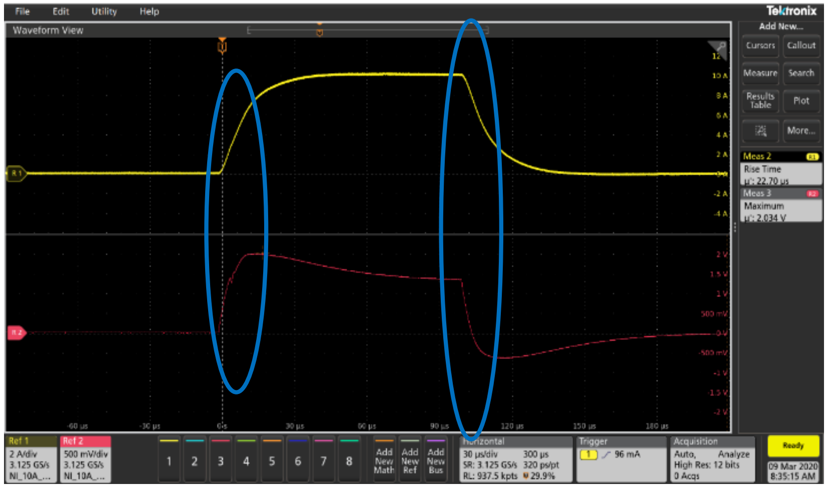
Trigger
1 640 mV

Acquisition
Auto, Analyze
High Res: 12 bits
0 Acqs

17 Mar 2020
7:23:33 AM

Voltage Considerations in Inductive load

Must account for $V = L\frac{di}{dt}$



Meas 2 R1
Rise Time
µ': 22.70 µs

Meas 3 R2
Maximum
µ': 2.034 V

Ref 1
2 A/div
3.125 GS/s
NI_10A_...

Ref 2
500 mV/div
3.125 GS/s
NI_10A_...

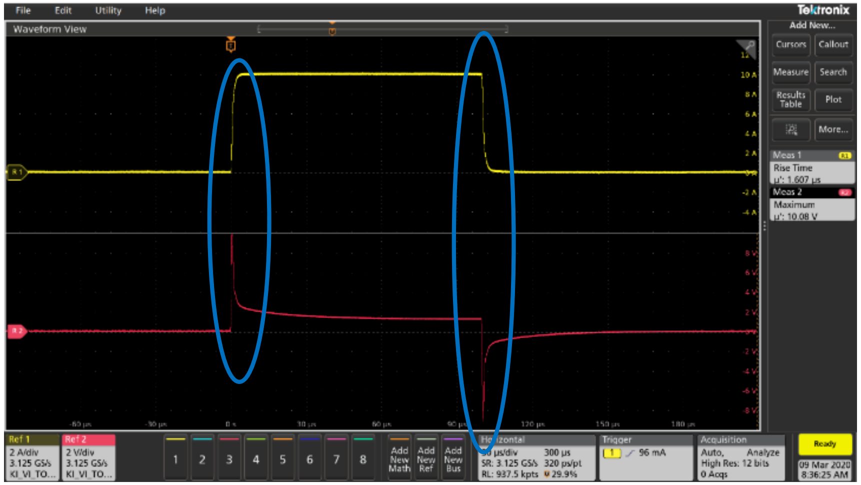
Horizontal
30 µs/div 300 µs
SR: 3.125 GS/s 320 ps/pt
RL: 937.5 kpts 29.9%

Trigger
1 96 mA

Acquisition
Auto, Analyze
High Res: 12 bits
0 Acqs

09 Mar 2020
8:35:15 AM

10A rise/fall in 22µs on 1µH DUT causes spikes of approximately ±2V peak



Meas 1 R1
Rise Time
µ': 1.607 µs

Meas 2 R2
Maximum
µ': 10.08 V

Ref 1
2 A/div
3.125 GS/s
KI_VI_TO...

Ref 2
2 V/div
3.125 GS/s
KI_VI_TO...

Horizontal
30 µs/div 300 µs
SR: 3.125 GS/s 320 ps/pt
RL: 937.5 kpts 29.9%

Trigger
1 96 mA

Acquisition
Auto, Analyze
High Res: 12 bits
0 Acqs

09 Mar 2020
8:36:25 AM

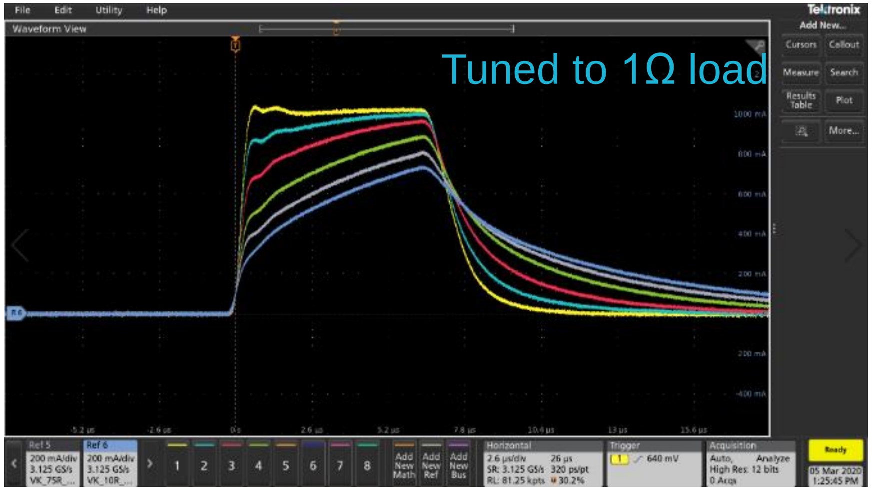
10A rise/fall in 1.6µs on 1µH DUT causes spikes of approximately ±10V peak

- More voltage peak in faster rise time
  - 1µs pulse width (100ns rise time) could have 100V peak

- Voltage Protection Limits:
- Maximum Total L is 3µH for 2601B-PULSE

Resistance Effects on Short Pulses

Results for 1A pulse from Typical “SMU” into 1Ω, 2.5Ω, 5Ω, 7.5Ω and 10Ω loads


Tuned to 1Ω load

Ref 5: 200 mA/div, 3.125 GS/s, VK_75R_...

Ref 6: 200 mA/div, 3.125 GS/s, VK_10R_...

Horizontal: 2.6 µs/div, 26 µs, SR: 3.125 GS/s, 320 ps/pt, RL: 81.25 kpts, 30.2%

Trigger: 1, 640 mV

Acquisition: Auto, Analyze, High Res: 12 bits, 0 Acqs

05 Mar 2020 1:25:45 PM

- High resistance generally slows things down
  - Increases RC time constants
  - Puts high voltage burden on current source
  - Can reduce bandwidth of control loops when DUT resistance is part of the feedback loop
    - Increases rise, fall and settling times
- The greater the resistance, the greater the impact.

What is the 2601B-PULSE?

- Single channel instrument with full functionality of 2601B SMU <u>plus</u> a high-speed current pulser
- Pulse up to 10A @ 10V with pulse widths as short as 10µs
- Works with inductive loads up to 3µH. High fidelity pulses with no tuning or remote test head required.
- Dual 1MS/s digitizers enable simultaneous I & V measurements during pulse (pulser only, not SMU)
- Built on our proven 26XX architecture and TSP (Test Script Processing) technology for best-in-class system-level throughput.
- Perform all DC and pulsed electrical measurements for VCSEL / LED test with a single instrument (e.g. Forward Bias IV, Reverse Bias Leakage and Breakdown).
- Easily integrate a DMM or other instrument for photodetector measurement using TSP-Link and precise triggering system for a complete LIV solution.

Key Pulser Specifications (cont)

SMU SPECIFICATIONS ARE UNCHANGED

- Pulse Width: 10µs to 500µs
    - All source levels
    - Programming Resolution: 1µs
    - Programming Accuracy: ± 200ns
    - Jitter: 110ns (typical)
- Pulse Period Jitter: 2µs (typical)
- Rise Time (10% to 90%): < 1.7µs
- Source/Meas Settling Time: < 9µs
    - Time to reach specified accuracy after start of pulse
- SMU-to-Pulser Transition: < 7ms

Pulse Current and Duty Cycle

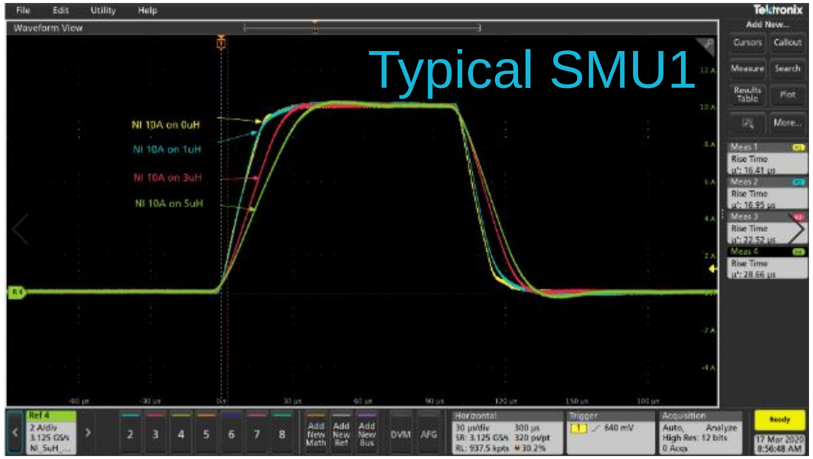
For $I_{BIAS} \leq$ 10mA:

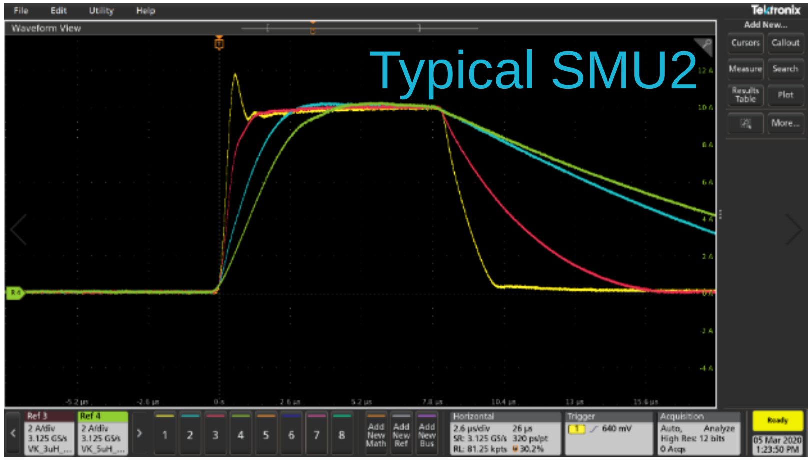
Pulse Current	Max. Duty Cycle
±10 A	3 %
±5 A	6%
±3 A	10 %
±1 A	30 %
±500 mA	60 %
±250 mA	100 %
0 A	

Superior Performance of 2601B-PULSE with High Inductance

RESULTS FOR 10A PULSE INTO 0µH,1µH, 3µH AND 5µH LOADS

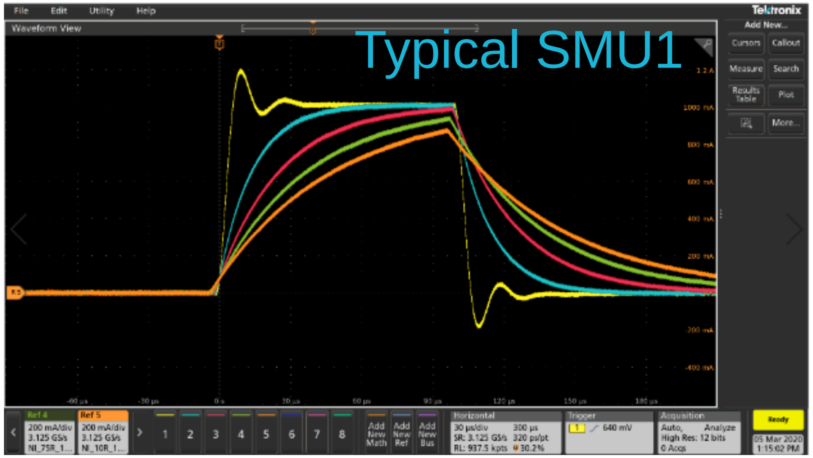
- Typical SMU has variable rise/fall time.
- Inductance pushes longer rise/fall time
- 2601B-PULSE has consistent shape

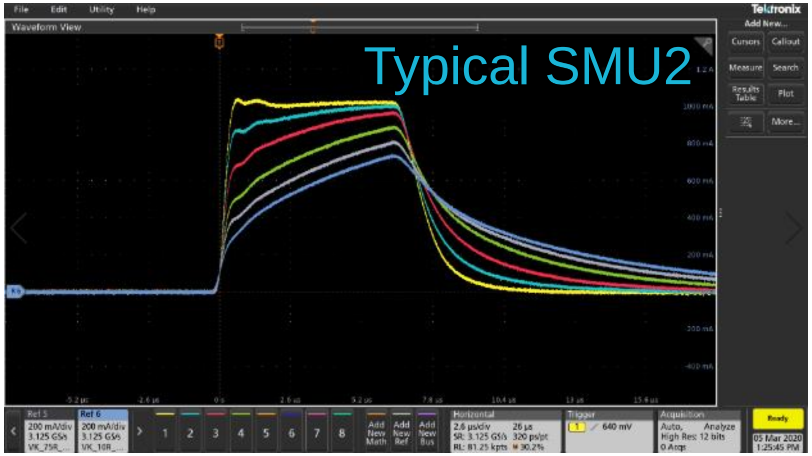




Superior Performance of 2601B-PULSE with High Resistance

RESULTS FOR 1A PULSE INTO 1Ω, 2.5Ω, 5Ω, 7.5Ω AND 10Ω LOADS



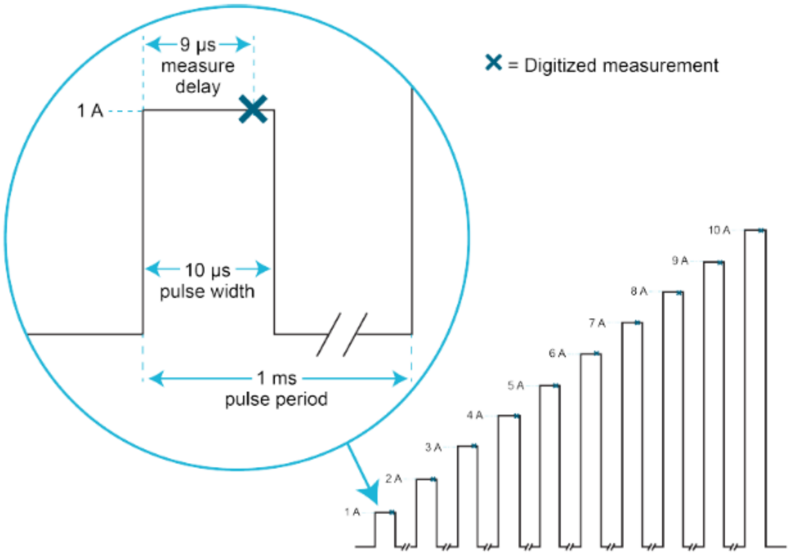


- Typical SMU pulse shapes degrade significantly with increasing resistance
- 2601B-PULSE has consistent shape

Example Pulse Sweep Script: 1A to 10A in 1A step

USES TRIGGER MODEL, TIMERS AND NEW MEASURE DELAY AND PULSE WIDTH SETTINGS

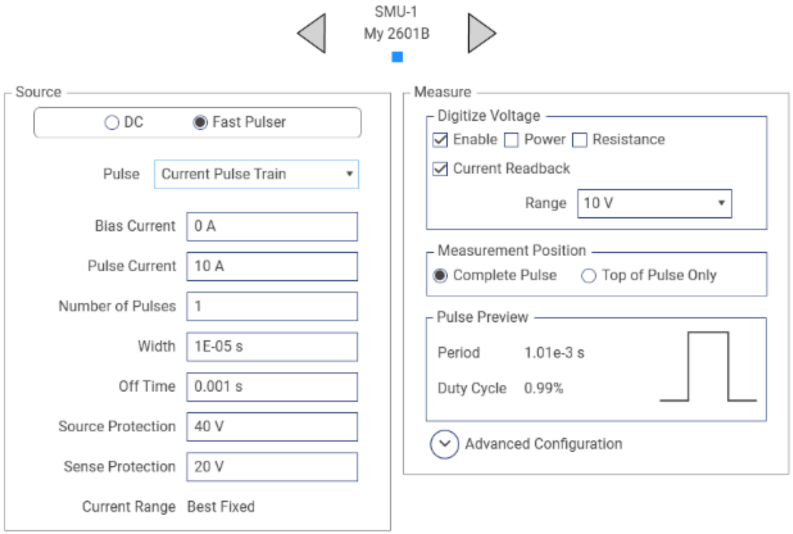
```
-- Set the number of pulses to 10.
smua.trigger.count = 10
-- Use Trigger Timer 1 to control pulse period (1 ms)
trigger.timer[1].delay = 1e-3
trigger.timer[1].count = 10
trigger.timer[1].passthrough = false
trigger.timer[1].stimulus = smua.trigger.ARMED_EVENT_ID
-- Enable source level changes during the sweep.
smua.trigger.source.action = smua.ENABLE
-- Specify a 10-point linear pulse sweep from 1 A to 10 A.
smua.trigger.source.lineari(1, 10, 10)
-- Set the source pulse width to 10 microseconds.
smua.trigger.source.pulsewidth = 10e-6
-- Start the pulse when the trigger timer event occurs.
smua.trigger.source.stimulus = trigger.timer[1].EVENT_ID
-- Perform measurements after a 9 us pulse measure delay.
-- Use default 1 us measure aperture.
-- Store measurements in nonvolatile buffer (nvbuffer1)
smua.trigger.measure.action = smua.ENABLE
smua.pulser.measure.delay = 9e-6
smua.trigger.measure.v(smua.nvbuffer1)
-- Enable pulse mode.
smua.pulser.enable = smua.ENABLE
-- Turn the source output on.
smua.source.output = smua.OUTPUT_ON
-- Initiate the trigger model.
smua.trigger.initiate()
```



Other software resources:

- Reference Manual
- Test Script Builder examples
- IVI-COM driver
- Native LabVIEW driver
- David Kim / Al Ivons

Operated by KickStart 2.3


SMU-1
My 2601B

Source

○ DC ● Fast Pulser

Pulse: Current Pulse Train

Bias Current: 0 A

Pulse Current: 10 A

Number of Pulses: 1

Width: 1E-05 s

Off Time: 0.001 s

Source Protection: 40 V

Sense Protection: 20 V

Current Range: Best Fixed

Measure

Digitize Voltage

☑ Enable ☐ Power ☐ Resistance

☑ Current Readback

Range: 10 V

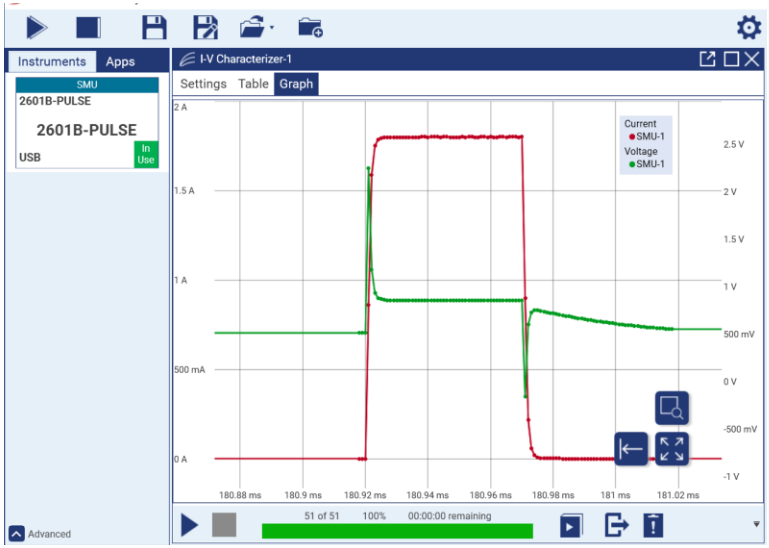
Measurement Position

● Complete Pulse ○ Top of Pulse Only

Pulse Preview

Period: 1.01e-3 s

Duty Cycle: 0.99%



51 of 51 100% 00:00:00 remaining

- Mode
  - DC vs Fast Pulser (default)
- Pulse Type
  - Current Pulse Train
  - Current Pulse Sweep
  - Current Pulse List Sweep
- Complete Pulse
  - Measure V&I for 2 x pulse width with 1M/s
- Top of Pulse Only
  - Measure on the pulse top
  - Aperture calculate automatically from Measure delay to the end of pulse.

Summary

- 3D sensing and imaging technology is driven by the VCSEL / Laser diode
- The shorter/fast and high power pulse width is required to this application, because of self-heating in the devices
- Challenges are in the impedance of cable and load which is the cable inductance and the various resistance.
- The 2601B-PULSE addresses consistent 10us clean pulse without any manual tuning in 3uH inductance.
- Keithley offers the knowledge and expertise to help you test 10us pulse test with VCSEL.