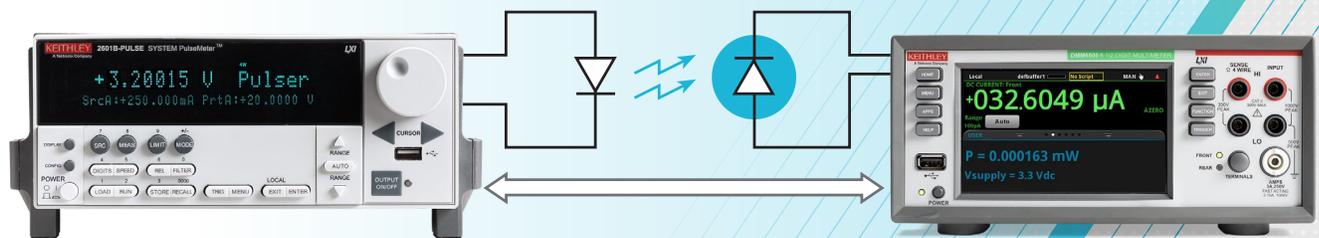


Timing Considerations for Constructing LIV Measurement Trigger Models Using the Keithley 2601B-PULSE System SourceMeter® Instrument and DMM7510 Graphical Sampling Digital Multimeter

APPLICATION NOTE



Introduction

LIV – light output/current/voltage – characterization is an important and commonly used way to verify the performance of all types of optical devices like light emitting diodes (LEDs), laser diodes, vertical cavity surface emitting lasers (VCSELs), and edge emitting lasers (EELs). For a number of reasons, a key aspect of LIV testing is the precise control of timing and synchronization. Typically, LIV testing involves one instrument to pulse currents into the laser diode (LD) and another instrument to measure the light response from a photodiode (PD). The time response of the photodiode can impose different timing requirements on the photodiode channel versus the laser diode channel; however, the measurements from the photodiode are not asynchronous with the laser diode excitation. During an automated LIV sweep, it is important to prevent a loss of synchronization between the photodiode and the laser diode channels; if there is such a loss, false failures will appear as a “kink” in the first derivative of the light measurement to current drive, thereby presenting an incorrect slope efficiency result.

As there are many applications for optical devices demanding higher power, we are confronted with the challenge of higher temperatures, making thermal issues a great concern. To account for inevitable junction temperature changes of the

devices, the current used to drive the device is required to be stimulated using DC to very short pulses, and, in many cases, while also applying high-speed digitizers in the measurement.

Pulsed current should stay flat long enough to ensure that the result accurately represents the laser diode’s true output. Laser diodes become optically unstable a few microseconds after lasing is initiated as heat dissipation increases. This is accompanied by the optical output dropping to a fraction of the expected power level. Highly deterministic pulse control allows highly repeatable test outcomes by reducing signal uncertainty, therefore tremendously improving electrical measurement efficiency.

Source measure units (SMUs) have been widely used for the DC I-V characterization of the various kinds of solid-state devices including said optical devices. The Keithley 2601B-PULSE SMU is capable of 10 μ s, 10 A current pulsing capability, and the Keithley DMM7510 and DMM6500 digital multimeters each have a 1 MSa digitizer to be able to measure the photo diode current for the light measurement. This application note is to focus on how two different instruments work together and how to build test scripts in the trigger model to synchronize two different instruments to introduce the LIV measurement solution with a single script.

Photodiode for Light Intensity Measurement

A photodiode (PD) – as a detector for laser light – has similar characteristics to a common diode with the exception that the reverse side of the PD is used for the output light power measurement. When there is little to no visible light, there is still a quantity of current flowing through the device that is referred to as the “dark current”. When the device detects the light, the current is more negative proportionally to the light power as shown in **Figure 1**. The manufacturers of the photodiodes usually provide information regarding responsivity (see **Figure 2**) indicating the measure of its sensitivity to light, defined as the ratio of photocurrent to incident light power at a given wavelength. The responsivity is

the conversion of light power into electrical current to be able to measure the output power measurement with the device. Still, there are so many complications and difficulties to measure light accurately because photo current can change in response to device temperature or bias voltage variations, along with complications with light reaching the detector.

While addressing the challenges of light intensity and optical power measurement make for good topics of further discussion, this application note will focus on how to measure LIV conceptually and the considerations for how to construct a script for the LIV measurement.

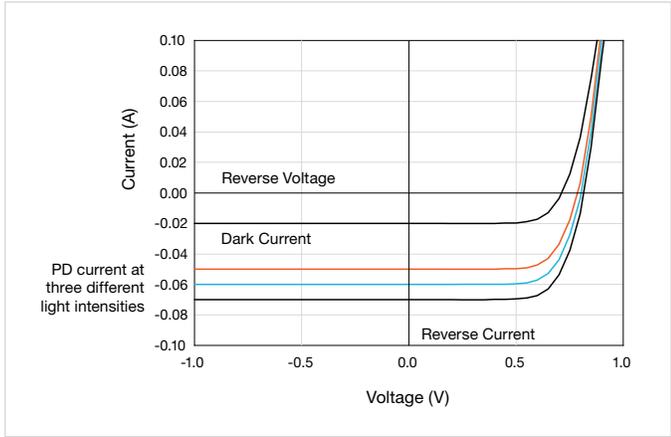


Figure 1. photo diode I-V characterization.

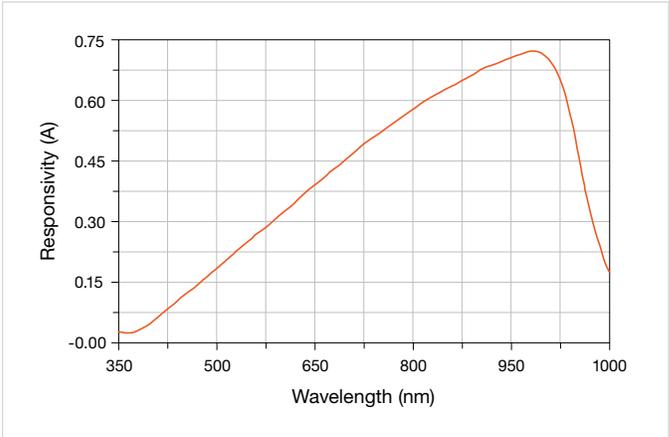


Figure 2. Photo diode responsivity.

LIV Test Setup for 2601B-PULSE with DMM

There are various DUT types that may include arrays, wafers, modules, or discrete components. These devices need both electrical and light measurement. When the device is activated by some electrical stimulus, it will illuminate laser light. This light is collected in an integration sphere allowing for many kinds of optical characterization to be performed including optical power, light spectrum, wavelength, etc. In many cases, a PD is commonly used for the light power measurement. When the PD is exposed to the light, the diode has a current proportional to the light power intensity and can be measured by a fast-digitizing DMM.

In our setup, we use the 2601B-PULSE to source and measure at the laser diode and the DMM7510 to measure

current induced by the photodiode. The 2601B-PULSE has a high-speed current pulse channel in addition to a separate SMU channel. The pulse channel can deliver up to 10 A at 10 V with a pulse width as short as 10 μ s, working well with a 3 μ H inductive load without any adjustment for matching load impedance. It is a high fidelity pulser with no tuning or remote test head required, and its dual 1 MSA/s digitizers enable simultaneous current and voltage measurement of its pulse stimulus. With as many as 15 measurement functions, the DMM7510 offers a current digitizer capable of sampling at 1 MSA/s.

Figure 3 is a typical test setup for the LIV measurement. Cables are connected from the 2601B-PULSE to the device, and the PD has a triaxial connector that is adapted to mate with the DMM7510. A TSP-Link® connection is required between the two instruments to allow them to synchronize.

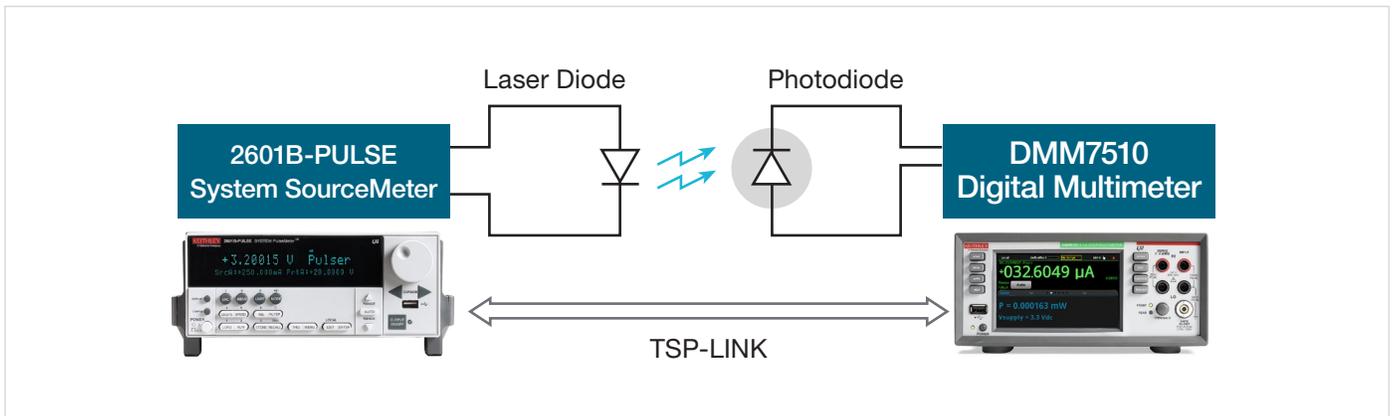


Figure 3. LIV test setup for 2601B-PULSE with DMM.

LIV Test Setup for 2601B-PULSE with DMM

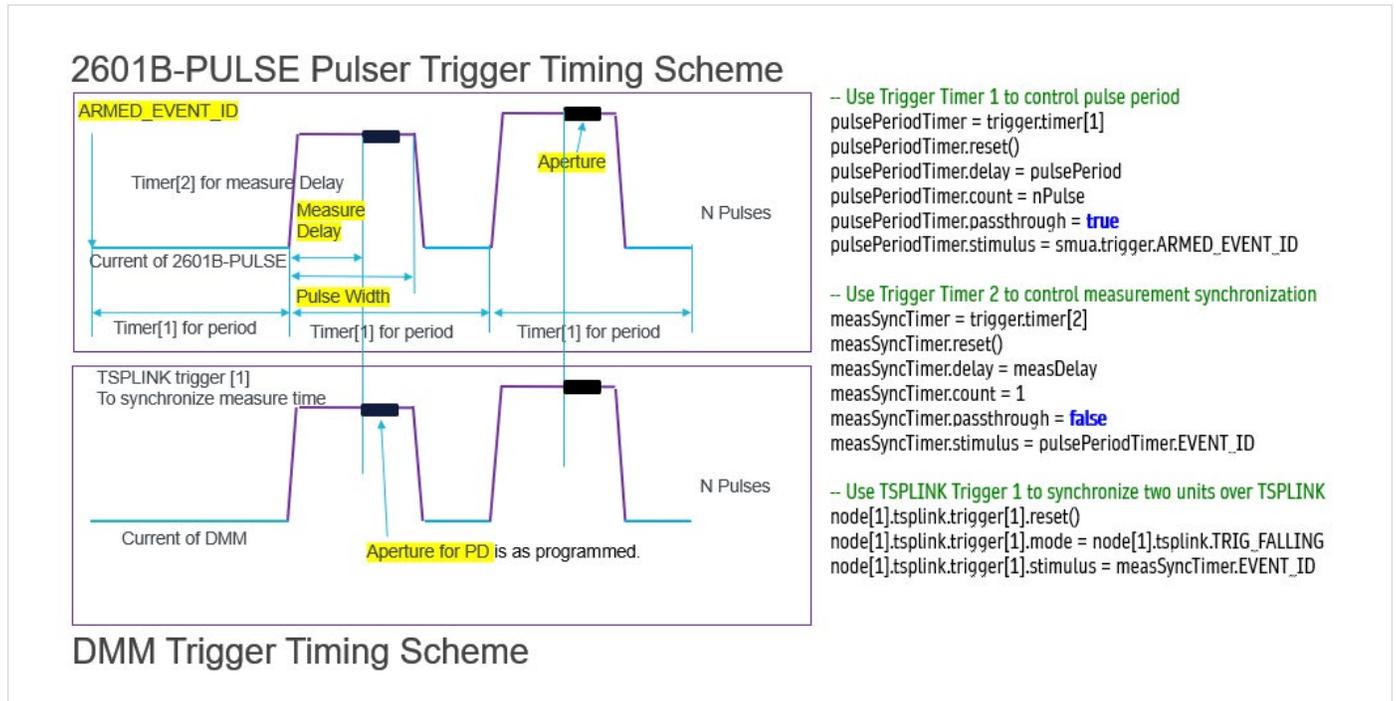


Figure 4: Trigger model timing for 2601B-PULSE and DMM.

Figure 4 shows the trigger model timing chart for the 2601B-PULSE paired with the DMM7510. Note in the code that at the time when the ARMED event occurs, the first timer – defined as pulsePeriodTimer, which resides with the 2601B-PULSE – controls both the pulse period and the time when the pulses start. Note that the pulse width and start of the pulser output is defined within the configPulserShort500us() function found in the script code shared in the appendix of this document. The second timer – measSyncTimer – applies the delay occurring immediately after the pulse period start and prior to the instance at which the instrument begins making the measurement over the applied aperture interval.

For synchronization of the DMM measurement with the pulse source, especially when pulse widths are brief, low latency of trigger signals between the instruments is critical. For this configuration, we use the TSP-Link trigger, which can achieve < 500 ns trigger latency timing. While this might seem significant when our pulses approach a 10 μs width, the measurement timing arrangement restricts trigger latency impact and renders it inconsequential for this application. Note in the example code how the TSP-Link trigger is initiated by the measure timer event that occurs after the specified interval has transpired. The DMM digitized current measurement and pulser digitized I-V measurements are all initiated by the TSP-Link trigger stimulus, yielding synchronized measurements at the laser diode and photodetector devices.

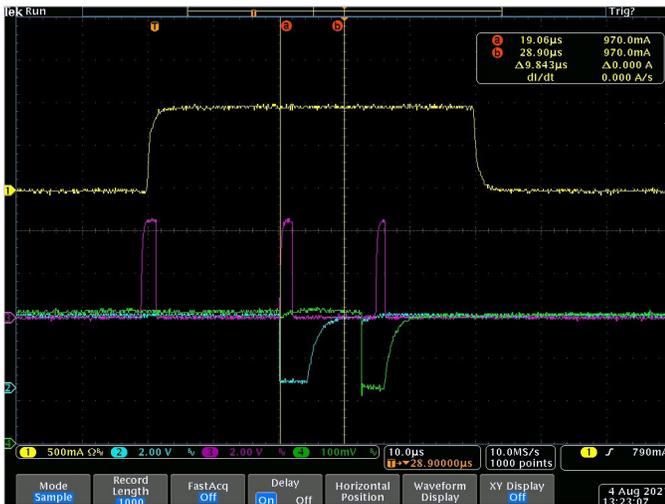


Figure 5. Trigger model timing in an oscilloscope.

Figure 5 shows the pulser output in relation to the trigger model timing as captured by an oscilloscope. The test was configured to issue a pulse width of 50 μs , implement a 20 μs measure delay (from the start of pulse), and 10 μs measurement aperture time. The purple trace monitors pulses that are supplementary signals generated on the 2601B-PULSE digital I/O and are mapped in relation to and help illustrate the following trigger events: pulse start, measure start, and measure complete. Trigger timings are as good as their settings. The TSP-Link trigger signal came from probing the TSP-Link cable physically. Note how the TSP-Link trigger line1 (represented by the blue trace) starts at the same time as the measure start, which is shown to occur 20 μs after the start of the pulse. The TSP-Link trigger line 2 (represented by the green trace) is the measurement complete event from the DMM slave node. We observe some degree of latency or misalignment between the DMM measure complete notification and that of the pulser's digital I/O signal, but it is inconsequential for this measurement since the operations all fall comfortably within the span of the pulse width.

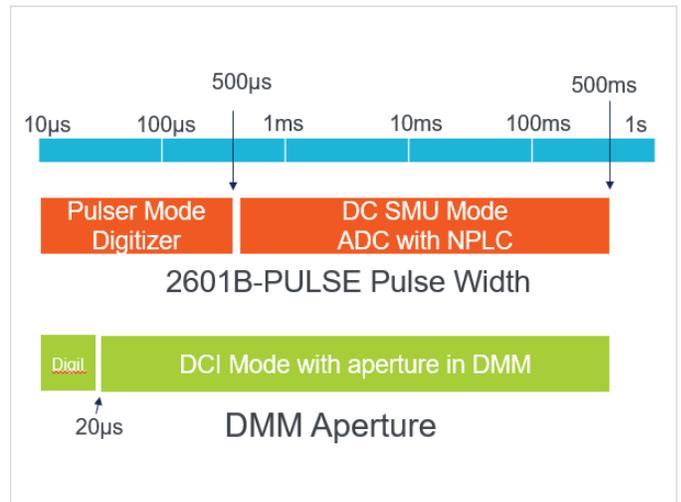


Figure 6. The pulse width range of the LIV measurement script.

The 2601B-PULSE System has two modes – fast pulser and DC SMU – to accommodate a broad spectrum of pulse widths ranging from as short as 10 μs up to DC as long as 500 ms. **Figure 6** helps to illustrate which mode is optimal for the pulse width desired by the user. For instances where pulses are required to be less than or equal to 500 μs , the fast pulse channel and mode should be utilized; where pulses are required to be greater than 500 μs , the DC SMU channel and mode should be used. In some instances, there are some customers who need to use both short and long pulsing together for certain kinds of devices. The full script (in the appendix) accounts for this and can be used to cover both types of pulse needs. Within the script, you will read that the logic evaluates the requested pulse width and applies either of the pulse modes accordingly. Note too, in the script, that the 2601B-PULSE will use the digitizer for measurements when the fast pulser mode is in effect (for pulse widths of 500 μs or less) and the traditional integrating ADC for the DC SMU mode.

As for DMM7510 (or other digitizing DMM), the digitizer is the perfect choice for applications where the aperture time does not exceed 20 μs . However, the integrating ADC mode is preferred when the application (photodiode current measurement or otherwise) calls for longer integration time due to its ability to better limit noise.

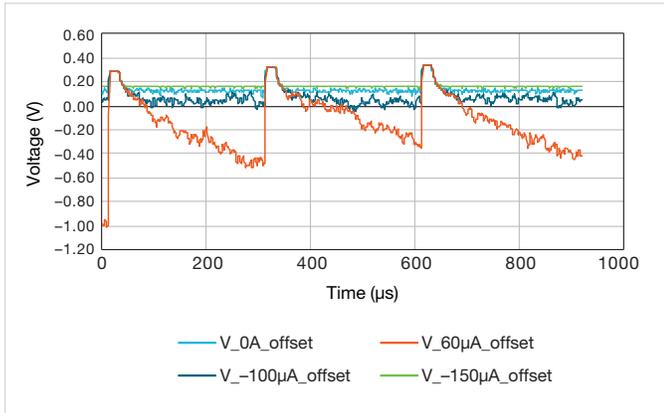


Figure 7. The voltage of the optical device versus offset current bias.

Most optical devices have a high impedance near the zero current bias condition and extending all the way into reverse bias. If there is even a very small amount of negative current bias, this negative bias can induce a substantial negative voltage bias. Case in point, **Figure 7** shows how a $-150 \mu\text{A}$ current bias causes a -1 V voltage. The 2601B-PULSE has the ability to account for and adjust this current offset and avoid the undesirable, excessive voltage difference. At least $100 \mu\text{A}$ current bias is strongly recommended to avoid the negative voltage bias during the pulse off condition.

Figure 8 shows the results of the LIV measurement for a 2 W power VCSEL device. The experimental data collected using the script from the appendix is virtually identical to that found in the datasheet from the device manufacturer. The 2601B-PULSE paired with the DMM7510 can evaluate device performance when the application calls for pulse widths as low as $10 \mu\text{s}$. **Figure 9** shares the results of complete pulse waveforms for the photodiode current as captured by the digitizing DMM. This complete waveform is useful in helping to evaluate whether or not an individual pulse works.

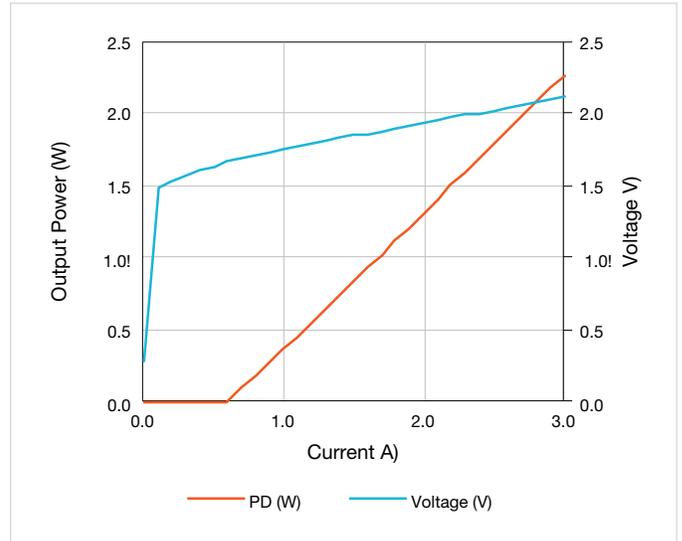


Figure 8. LIV measurement with $10 \mu\text{s}$ pulse width.

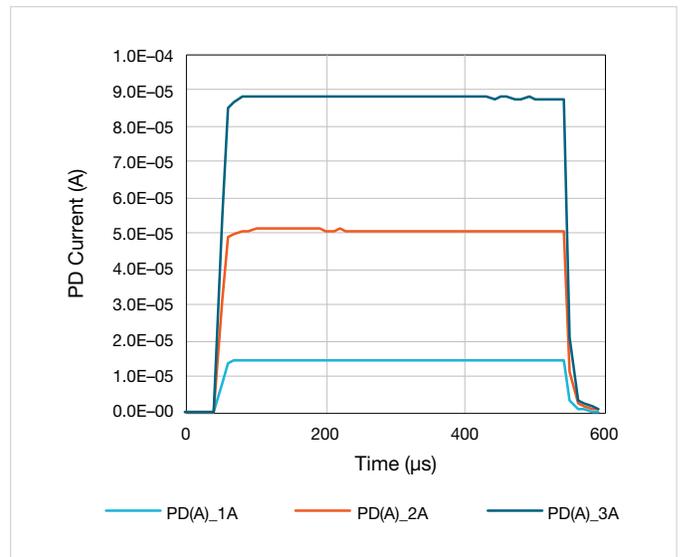


Figure 9. $500 \mu\text{s}$ pulse complete waveforms.

Figure 10 shows the results of the over drive current to the 2 W VCSEL device. The maximum forward drive current is 8 A and reaches over 6 W of optical power but note that there is a thermal issue in using a longer pulse width. When the pulse current is higher than 4 A for both the 300 μ s and 500 μ s pulse widths, the optical power is diminished in comparison to the shorter 10 μ s pulse. Similar can be observed in the complete pulse waveforms shown in **Figure 11**. For the higher current levels, the PD currents representing optical power decrease as the pulse width is lengthened. As noted previously with respect to shorter pulse performance, the complete waveform scripts are helpful to identify this behavior in the individual pulses.

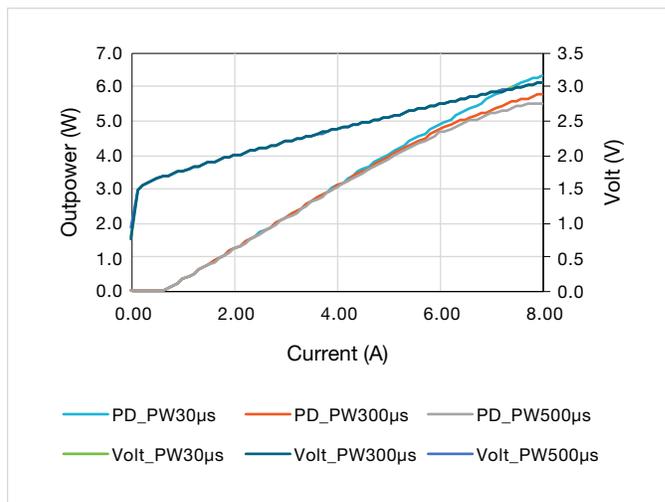


Figure 10. Thermal heat with high power device.

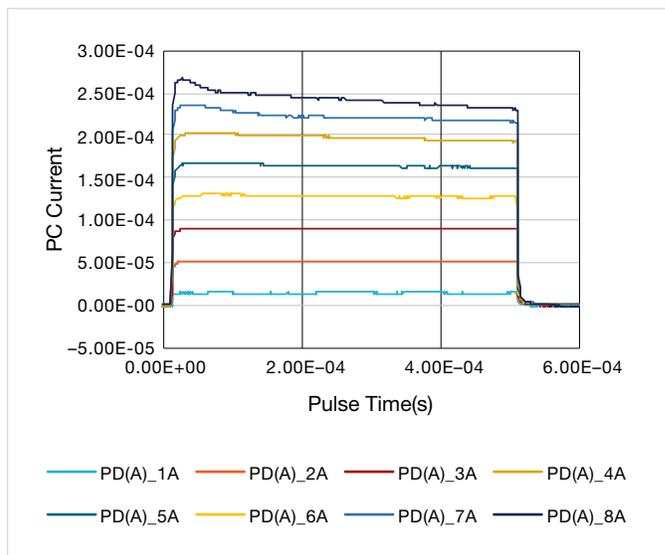


Figure 11. Thermal issue check in complete waveforms.

LIV Test Setup for 2601B-PULSE with SMU2602B

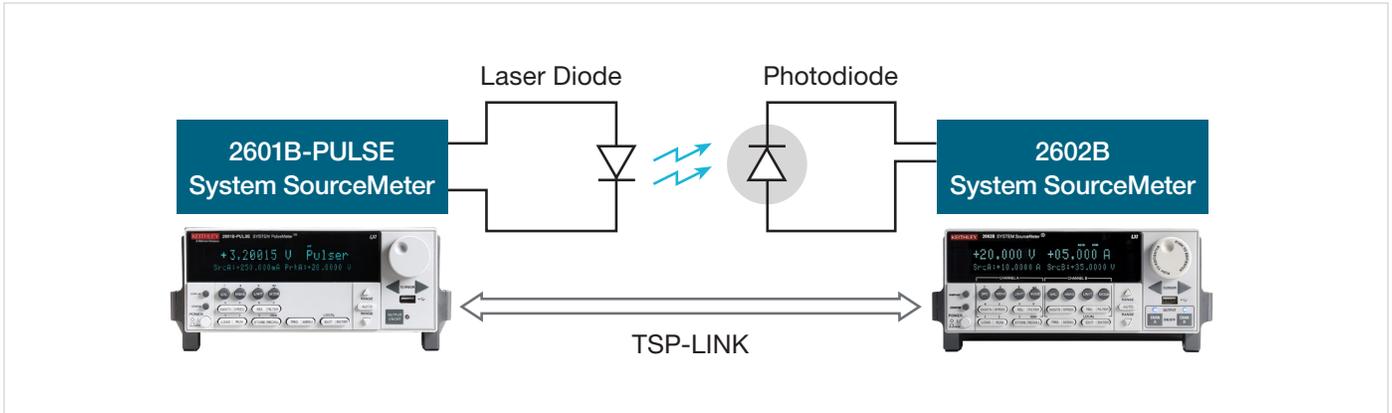


Figure 12. LIV test setup for 2601B-PULSE with SMU 2602B.

For those who might consider using the 2602B for the PD measurement, it should be noted that this meter is simply not fast enough to achieve measurements in setups where the pulse width is shorter than 50 μs . The limitations extend further for attempts to acquire the complete pulse where only captures of longer than 500 μs pulse widths are available, making it less optimal to match with the 2601B-PULSE, which has high speed digitizers. However, the standard Series 2600B SMUs can reliably achieve sampling rates up to 20 kSa/s with its fast integrating ADC. Asynchronous mode in the trigger model can support the measurement in pulse off time, and we can make measurements every 50 μs with the minimum NPLC 0.001. It is possible to capture pulse waveforms with 20 kSa/s sample rate using the regular 2600B SMU. **Figure 13** and **Figure 14** are provided to illustrate that using the 2602B for the PD measurement can support 50 μs pulse width LIV measurements and 500 μs pulse width complete waveform tests.

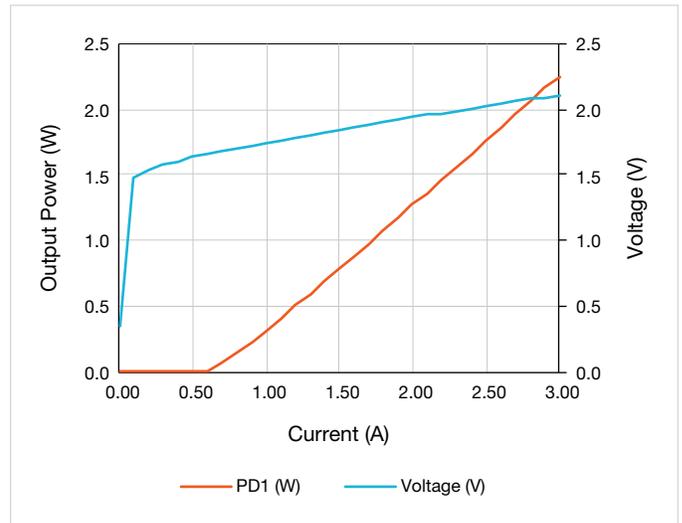


Figure 13. LIV measurement of 50 μs with 2602B.

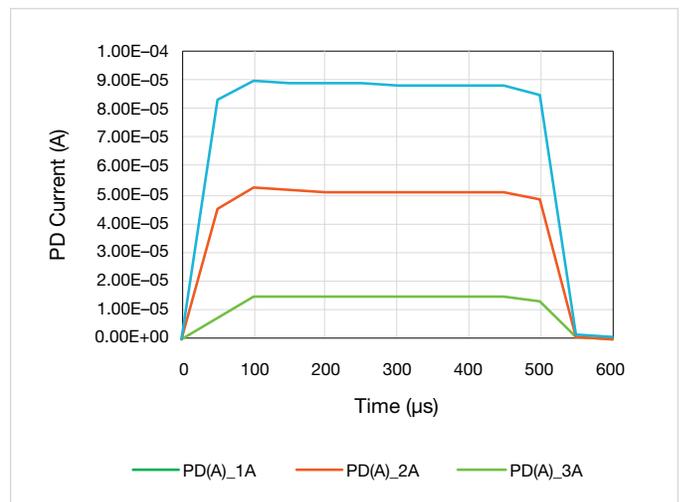


Figure 14. 500 μs pulse complete waveforms with 2602B.

Conclusion

VCSEL/laser devices are increasingly being used in mobile device, optical communication, and automotive applications. Manufacturers can qualify these devices using the common LIV measurement and instruments such as the Keithley 2601B-PULSE, 2602B, and DMM7510 that allow users to achieve the industry's best trigger synchronization of multiple instruments with accurate timing control. Keithley TSP® scripts can be deployed through any programming IDE and used to easily embed test code local to the equipment hardware and improve efficiency in testing.

While the primary script code referenced in this application note can be found in the appendix of this application note, this and other example scripts for the LIV and complete waveform measurement are accessible in their raw form on GitHub at:

https://github.com/tektronix/keithley/tree/master/Instrument_Examples/26xx-SMU/TSP_Scripts_for_LIV_Testing

For more detail about LIV testing that was not covered in detail within this document, please visit tek.com to locate the application note entitled, "Testing Laser Diode Modules and VCSELs with the 2601B-PULSE System SourceMeter® Instrument and KickStart Instrument Control Software". Further, to better understand the 10 µs pulsing technology and capabilities of the instrument 2601B-PULSE System SourceMeter, refer to the application note entitled, "Generating Clean 10 µs Pulses with the 2601B-PULSE System SourceMeter® Instrument".

Appendix

This TSP script is used to automate the LIV measurement and is intended to be run on the Keithley 2601B-PULSE System SourceMeter with a Keithley DMM7510 Sampling Digital Multimeter.

```
loadandrunscript
--[[
#####

Script File: measurementLIV_CaseI_2601B_PULSE_DMMs.tsp

*****
*** Copyright Tektronix, Inc. ***
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*****

Description:
This script is example code, which creates (and subsequently calls) a
single function that can be used with the Model 2601B-PULSE current pulser
to output a current pulse sweep. The sweep is generated using the
instrument's Asynchronous Trigger Model. Using the dual 1MS/s digitizers
built into the current pulser, the voltage and current are measured
simultaneously at the top of each pulse and PD current measured from the DMM.
Upon completion of the sweep, the data is printed to the Test Script Builder
Instrument Console in a format that is suitable for copying and pasting into
Microsoft Excel for graphing and analysis.

Required Equipment: 1 Model 2601B-PULSE System SourceMeter instrument
                   1 DMM7510 or DMM6500 Multimeter instrument

Note: The function does not perform any error checking. It is the user's
responsibility to specify settings that are compatible with the
instrument model being used, and with its power envelope.

Note: It is the user's responsibility to follow all safety guidelines given in
the instrument's Reference Manual. This is especially critical if
voltages in excess of 42VDC will be present in the test circuits. Such
voltage levels are hazardous.

Function created by this script:
* measurementLIV_CaseI_2601B_PULSE_DMMs(startI, stopI, nPulse, pulsePeriod, pulseWidth,
    measAperture, measDelay, rangeV, rangeI, protectVsrc,
    protectVsns, biasCurrent, rangeDMM, optoFactor)

Example Usage:
* measurementLIV_CaseI_2601B_PULSE_DMM(0.0,0.2,21,50e-3,50e-6,20e-6,10e-6,5,1,10,10,0.1e-3,1e-3,2700,1)

#####
--]]

function measurementLIV_CaseI_2601B_PULSE_DMM(startI, stopI, nPulse, pulsePeriod, pulseWidth, measAperture,
    measDelay, rangeV, rangeI, protectVsrc, protectVsns,
biasCurrent,
    rangeDMM, optoFactor, printData)

--[[

Prerequisites: None

Pass Parameters:
* startI      : Current level of the first pulse in amps
* stopI       : Current level of the last pulse in amps
```

```

* nPulse      : Number of pulses in the sweep
* pulsePeriod : Time between start of consecutive pulses in seconds
* pulseWidth  : Width of current pulses in seconds
* measAperture : Effective integration time in seconds
* measDelay   : Time from pulse start to measure start in seconds
* rangeV      : Voltage measure range in volts
* rangeI      : Current source and measure range in amps
* protectVsrc : Protection Voltage on Source side
* protectVsns : Protection Voltage on Sense side
* biasCurrent : Idle current level in amps (base level for pulses)
* rangeDMM    : Range of DMM
* optoFactor  : Proportional Constant to calculate optical power based on the PD current
Returned values: None
--]]

-- Reset the pulser to default conditions
smua.reset()

-- Configure the reading buffers
smua.nvbuffer1.clear()
smua.nvbuffer2.clear()
smua.nvbuffer1.collecttimestamps= 1
smua.nvbuffer2.collecttimestamps= 1

-- Use Trigger Timer 1 to control pulse period
pulsePeriodTimer = trigger.timer[1]
pulsePeriodTimer.reset()
pulsePeriodTimer.delay           = pulsePeriod
pulsePeriodTimer.count          = nPulse
pulsePeriodTimer.passthrough    = true
pulsePeriodTimer.stimulus       = smua.trigger.ARMED_EVENT_ID

-- Use Trigger Timer 2 to control measurement synchronization
measSyncTimer = trigger.timer[2]
measSyncTimer.reset()
measSyncTimer.delay           = measDelay
measSyncTimer.count          = 1
measSyncTimer.passthrough    = false
measSyncTimer.stimulus       = pulsePeriodTimer.EVENT_ID

node[1].tsplink.trigger[1].reset()
node[1].tsplink.trigger[1].mode = node[1].tsplink.TRIG_FALLING
node[1].tsplink.trigger[1].stimulus = measSyncTimer.EVENT_ID
node[1].tsplink.trigger[1].pulsewidth = 3e-6

if pulseWidth > 500e-6 then
    if measAperture < 20e-6 then
        measAperture = 20e-6
    end
    if measDelay < 100e-6 then
        measDelay = 100e-6
    end
    configDcLonger500us(startI, stopI, nPulse, rangeI, rangeV, biasCurrent, measAperture,
                        nPulse,pulseWidth)
else
    configPulserShorter500us(startI, stopI, nPulse, rangeI, rangeV, protectVsrc, protectVsns,
                             biasCurrent, measAperture, nPulse, pulseWidth)
end
local meaDelayDMM = 0 -- DMM delay after TSPLINK trigger, but not necessary in most case
node[2].tsplink.group = 1
node[2].execute("DMM_setup("..nPulse..","..meaDelayDMM..","..measAperture..","..rangeDMM..")")
waitcomplete(1)

```

```

-- Turn on the output
smua.source.output = smua.OUTPUT_ON

-- Initiate the Trigger Model and wait for the sweep to complete
if measAperture < 20e-6 then
    node[2].trigger.model.initiate()
end
smua.trigger.initiate()
waitcomplete()

-- Turn off the output and disable the current pulser
smua.source.output = smua.OUTPUT_OFF
smua.pulser.enable = smua.DISABLE

-- Output the data in tab-separated format
if printData > 0 then
    print("\n Time (s)\tCurrent (A)\tVoltage(V) \t DMM1(A)\t DMM1(W)")
    for i = 1, smua.nvbuffer1.n do
        print(smua.nvbuffer1.timestamps[i], smua.nvbuffer1[i], smua.nvbuffer2[i], math.abs(node[2].
defbuffer1[i]),
            math.abs(node[2].defbuffer1[i] * optoFactor))
    end
end
end

function configPulserShorter500us(startI, stopI, nPulse, rangeI, rangeV,
                                protectVsrc,protectVsns,biasCurrent,measAperture,nPulse,pulseWidth)
    -- Enable the fast current pulser
    smua.pulser.enable = smua.ENABLE
    smua.pulser.rangei          = rangeI
    smua.pulser.rangev          = rangeV

    smua.pulser.protect.sourcev      = protectVsrc
    smua.pulser.protect.sensev       = protectVsns
    smua.source.leveli               = biasCurrent

-- smua.pulser.measure.delay         = measDelay
smua.pulser.measure.aperture        = measAperture
smua.measure.count                  = 1
-- Configure Trigger Model to perform a linear staircase current pulse sweep
smua.trigger.count                  = nPulse
smua.trigger.source.linearI(startI, stopI, nPulse)
smua.trigger.source.action          = smua.ENABLE
smua.trigger.source.pulsewidth      = pulseWidth
smua.trigger.source.stimulus        = pulsePeriodTimer.EVENT_ID
smua.trigger.measure.stimulus       = tsplink.trigger[1].EVENT_ID
smua.trigger.measure.action         = smua.ASYNC
smua.trigger.measure.iv(smua.nvbuffer1, smua.nvbuffer2)
end

function configDcLonger500us(startI,stopI,nPulse,rangeI,rangeV,biasCurrent,measAperture,nPulse,pulseWidth)
    rangeV = 6
    -- Enable the fast current pulser
    smua.pulser.enable = smua.DISABLE
    smua.source.func      = smua.OUTPUT_DCAMPS
    smua.sense             = smua.SENSE_REMOTE
    smua.source.autorangei = smua.AUTORANGE_OFF
    smua.source.rangei    = rangeI
    smua.source.leveli    = biasCurrent
    smua.source.limitv    = rangeV

```

```

-- Disabling Auto-Ranging and Auto-Zero ensures accurate and consistent timing
smua.measure.autozero           = smua.AUTOZERO_ONCE
smua.measure.autorangev        = smua.AUTORANGE_OFF
smua.measure.rangev            = rangeV
smua.measure.nplc              = measAperture * localnode.linefreq

-- A timer will be used to control the measure delay so set the built-in delay to 0
smua.measure.delay              = 0
pulseWidthTimer = trigger.timer[4]
pulseWidthTimer.reset()
pulseWidthTimer.delay           = pulseWidth
pulseWidthTimer.count           = 1
pulseWidthTimer.passthrough     = false
pulseWidthTimer.stimulus        = trigger.timer[2].EVENT_ID

-- Configure SMU Trigger Model for Sweep
smua.trigger.source.linearI(startI, stopI, nPulse)
smua.trigger.source.limitv      = rangeV
smua.trigger.measure.action     = smua.ASYNC
smua.trigger.measure.iv(smua.nvbuffer1, smua.nvbuffer2)
smua.trigger.endpulse.action    = smua.SOURCE_IDLE
smua.trigger.endsweep.action    = smua.SOURCE_IDLE
smua.trigger.count              = nPulse
smua.trigger.arm.stimulus       = 0
smua.trigger.source.stimulus    = pulsePeriodTimer.EVENT_ID
smua.trigger.measure.stimulus   = tsplink.trigger[1].EVENT_ID
smua.trigger.endpulse.stimulus  = pulseWidthTimer.EVENT_ID
smua.trigger.source.action      = smua.ENABLE
end

local setDMM7510 = [[
function DMM_setup(nReading, measDelayDMM, measAperture, rangeDMM)

-- Configure DMM 1 reading buffer defbuffer1
node[2].defbuffer1.clear()
node[2].defbuffer1.capacity = 100000
node[2].defbuffer1.fillmode = node[2].buffer.FILL_ONCE

if measAperture >= 20e-6 then
    node[2].dmm.measure.func = node[2].dmm.FUNC_DC_CURRENT
    node[2].dmm.measure.range = rangeDMM
    node[2].dmm.measure.aperture = measAperture
    node[2].dmm.measure.autozero.once()
    node[2].dmm.measure.autozero.enable = 0
    node[2].dmm.measure.count           = 1
    node[2].dmm.measure.autodelay       = 0
    node[2].dmm.trigger.measure.stimulus = node[2].trigger.EVENT_TSPLINK1

else
    node[2].dmm.digitize.func = node[2].dmm.FUNC_DIGITIZE_CURRENT
    node[2].dmm.digitize.range = rangeDMM
    node[2].dmm.digitize.samplerate = math.floor(1 / measAperture)
    node[2].dmm.digitize.count = 1

-- Create DMM Trigger Model
node[2].trigger.model.load("EMPTY") --If the configuration name is set to "EMPTY", any existing
trigger model settings are reset.
node[2].trigger.model.setblock(1, node[2].trigger.BLOCK_BUFFER_CLEAR, defbuffer1)
node[2].trigger.model.setblock(2, node[2].trigger.BLOCK_WAIT, node[2].trigger.EVENT_TSPLINK1,
node[2].trigger.CLEAR_NEVER)
node[2].trigger.model.setblock(3, node[2].trigger.BLOCK_DELAY_CONSTANT, measDelayDMM) -- meas Delay

```

```
node[2].trigger.model.setblock(4, node[2].trigger.BLOCK_MEASURE_DIGITIZE, defbuffer1, node[2].
trigger.COUNT_AUTO)
node[2].trigger.model.setblock(5, node[2].trigger.BLOCK_NOTIFY, node[2].trigger.EVENT_NOTIFY1)
node[2].trigger.model.setblock(6, node[2].trigger.BLOCK_BRANCH_COUNTER, nReading, 2)
node[2].trigger.model.setblock(7, node[2].trigger.BLOCK_BRANCH_ALWAYS, 0)
end
-- Configure TSP-Link Trigger Line 1 to detect trigger from 2601B-PULSE
node[2].tsplink.line[1].reset()
node[2].tsplink.line[1].mode = node[2].tsplink.MODE_TRIGGER_OPEN_DRAIN -- For compatibility with
2600A/B series
node[2].trigger.tsplinkin[1].edge = node[2].trigger.EDGE_FALLING
end
]]

function measurementLIV()
    local startI      = 0
    local stopI       = 0.2
    local nPulse      = 21
    local pulsePeriod = 50e-3
    local pulseWidth  = 50e-6
    local measAperture = 10e-6
    local measDelay   = 10e-6
    local rangeV      = 5
    local rangeI      = 1
    local protectVsrc = 10
    local protectVsns = 10
    local biasCurrent = 0.5e-3
    local rangeDMM    = 1e-3
    local optoFactor  = 27000
    measurementLIV_CaseI_2601B_PULSE_DMM(startI, stopI, nPulse, pulsePeriod, pulseWidth, measAperture,
                                          measDelay, rangeV, rangeI, protectVsrc, protectVsns, biasCurrent,
                                          rangeDMM, optoFactor, 1)
end

function initializeTSPLINK()
    local nodesFound = tsplink.reset()
    if nodesFound ~= 2 then
        print(string.format("TSPLINK Error: not Found 2nd Node."))
        exit()
    end
    local DMM_group = 1
    local DMM_node = node[2]
    DMM_node.tsplink.group = DMM_group
    DMM_node.execute(setDMM7510)
    waitcomplete(1)
    print("TSPLINK is successfully linked")
end

endscript
print("the script is loaded")
```

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Rev. 02.2018



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011322 SBG 1KW-73877-0

