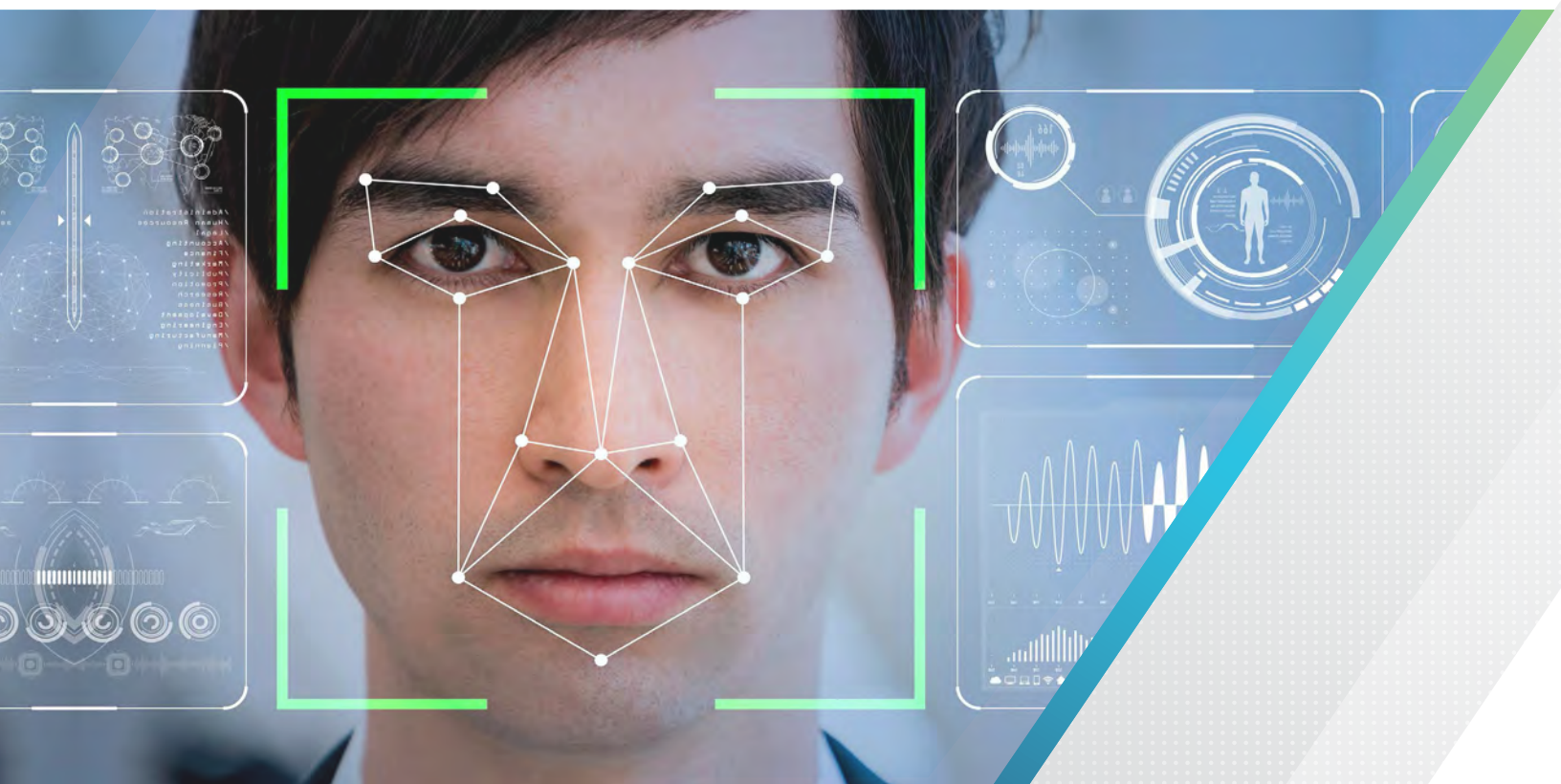


Laser Diode Array Test for 3D Sensing with a 2602B or 2606B System SourceMeter® Instrument and DMM7510 Graphical Sampling DMM

APPLICATION NOTE



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Introduction

The growing demand for distance and velocity measurements in three-dimensional space is evident in many applications from autonomous driving in the automotive industry, augmented reality in gaming and consumer products, and human-machine interfaces and robotics in industrial applications. Vertical Cavity Surface Emitting Lasers (VCSELs) have been widely used for obtaining depth information in 3D applications. For example, Time-of-Flight (TOF) is a technique that measures the time of a single laser pulse or pulse train leaving a laser illuminator, traveling to a scene and being reflected back onto a focal plane array. This results in the complete capture of spatial and temporal information to render a full 3D image. Even gesture recognition can be acquired dynamically with the use of continuous pulses in real time.

VCSELs for 3D Sensing

There are two common methods for performing 3D sensing. The first, called structured light, applies laser triangulation from the illuminator and the receiver to compute depth. It may also combine a projection of a light pattern with the reflected but distorted light pattern on a standard 2D camera to calculate depth. The other, called TOF, estimates the time delay from the light emission to the light detection. A TOF camera relies on two principles. The continuous-wave modulated light measures the phase difference between the emitted and received sinusoidal signal to obtain the travel time, thereby indirectly obtaining the distance. The pulsed light directly measures the time taken for a light pulse to travel from the device to the object and back. The pulsed light from a single VCSEL illuminator light source can also scan in two dimensions. The most advanced technology using that principle is a matrix-type array TOF camera that measures depth with a matrix of 3D Image sensor in a single shot.

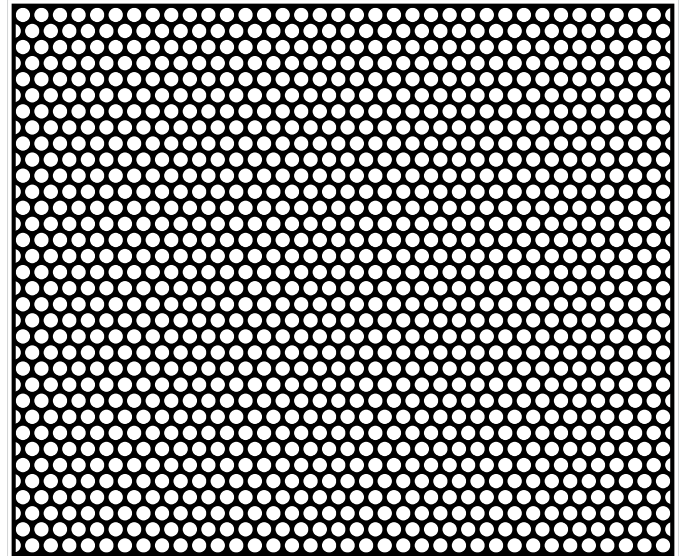


Figure 1. Example of 2D VCSEL array.

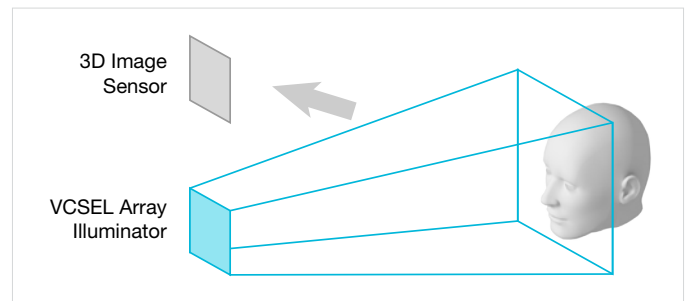


Figure 2. Matrix-type array TOF measurement.

LIV Measurement of VCSEL Array

The distance an illuminator can reach is directly proportional to the amount of power the light source can output. A single VCSEL may output only a few milli-watts, but a VCSEL array consisting of hundreds of VCSELs per square millimeter can output a couple of watts to illuminate a much further distance. The VCSEL arrays used in 3D sensing have the power to illuminate distance up to a couple of hundred meters.

A VCSEL array may be constructed with thousands of VCSELs connected in parallel to light up simultaneously. Other VCSEL arrays may be organized in addressable groups or banks that can be turned on and off individually. Individual groups may also have dedicated terminals to allow driving them individually or synchronously. A series of timed current pulses are required to drive the groups. While any group is briefly illuminated, accurate voltage measurements are made at the pulse top. Depending on the voltage reading, additional

information such as temperature and photodiode current measurement are acquired for further performance analysis. In addition, optical power spectrum measurement from a spectrum analyzer or a spectrometer are being monitored.

Script Processing

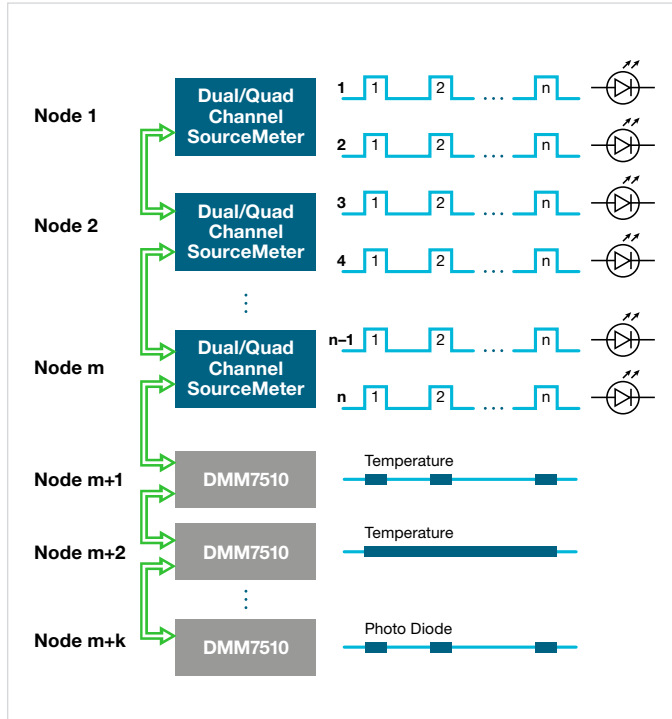


Figure 3. VCSEL array test with multiple SMUs and DMMs integrated via linked by TSP-Link.

Instruments with Keithley’s on-board Test Script Processor (TSP) are ideal for accomplishing intricate sourcing and measurement actions like these while delivering maximum throughput in a production environment. For example, 2602B or 2606B System SourceMeter instruments (SMUs) can be configured as high speed, high accuracy pulse current drivers to synchronize laser diode excitation and forward voltage measurement. Multiple DMMs can be precisely triggered

with less than 1 μ s latency to measure the temperature (using resistance reading of the VCSEL array thermistors), and the optical power (by reading the photodiode current).

The key advantage the SourceMeter instruments offer for this application is their onboard test script processing capability. The TSP allows for flexible custom control of test sequences, conditional branching such as *if..then, do..while*, advanced calculations, Pass/Fail decision making, custom function creation, and precision handshaking with other instruments, probers or handlers through digital I/O, TSP-Link triggering, etc. This greatly reduces the communication that must take place between a PC and the instrument via a remote bus interface such as GPIB, LAN or USB. The result is much less system overhead time and much higher overall production throughput. By combining the power of TSP and TSP-Link, an LIV test sweep can run at hardware speeds, independent of the PC or the remote bus interface.

The Keithley Test Script Builder environment allows, as shown in **Figure 4**, executing the TSP code on the instrument, including verifying the program operation and output. This development approach allows program code block validation before porting it to another test environment such as VB.NET, LabVIEW®, etc.

Each instrument is also equipped with an internal data buffer for storing readings. Once the test is complete, the readings in the data buffer can be transferred and analyzed on the PC.

Trigger Link is another hardware handshake interface that the instruments in the test system can use to ensure proper test sequencing. When the meter and switch mainframe are connected via a Trigger Link cable, they can trigger each other to allow faster test execution. This built-in bus eliminates the need for direct PC control of most system functions. When the Trigger Link function is used properly, the only functions the PC performs are initiating the test and retrieving data from the system.

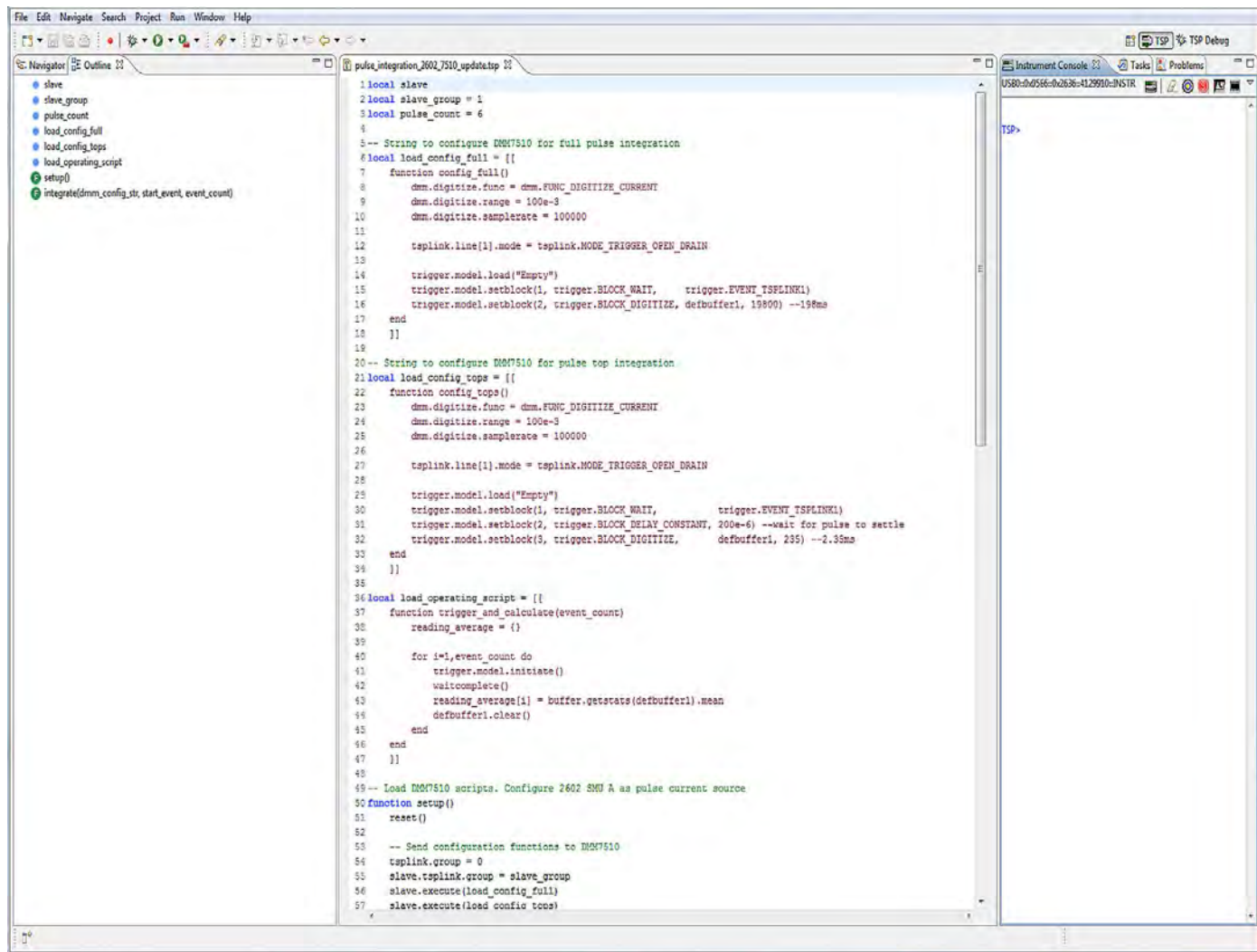


Figure 4. Test Script Builder (TSB) environment.

Keithley 2600B Series Trigger Model

The trigger model of the Keithley 2600B Series is extremely powerful for synchronizing sourcing multiple pulses and measuring voltage and current. The trigger overview shown in **Figure 5** illustrates all the trigger objects in a 2600B SMU, which include two trigger generators, eight timers, one manual front panel key trigger, six event blenders, 14 hardware digital I/O triggers, three hardware TSP-Link triggers, five LAN triggers and a software command trigger.

The trigger objects, such as the timers, can be used to define the pulse period, pulse width and measure delay from a single reference time point. The three hardware TSP-Link triggers synchronize pulse start time, pulse end time and measure start along the daisy-chain of instruments in the entire integrated system, with just few hundred nano-seconds of latency.

Figure 6 is a trigger model implementation of the LIV sweep of the VCSEL array on a 2600B Series SMU. The precise control of pulse width, pulse period and measure delay can be easily accomplished with a combination of timers and communicated to other instruments via TSP-Link triggers.

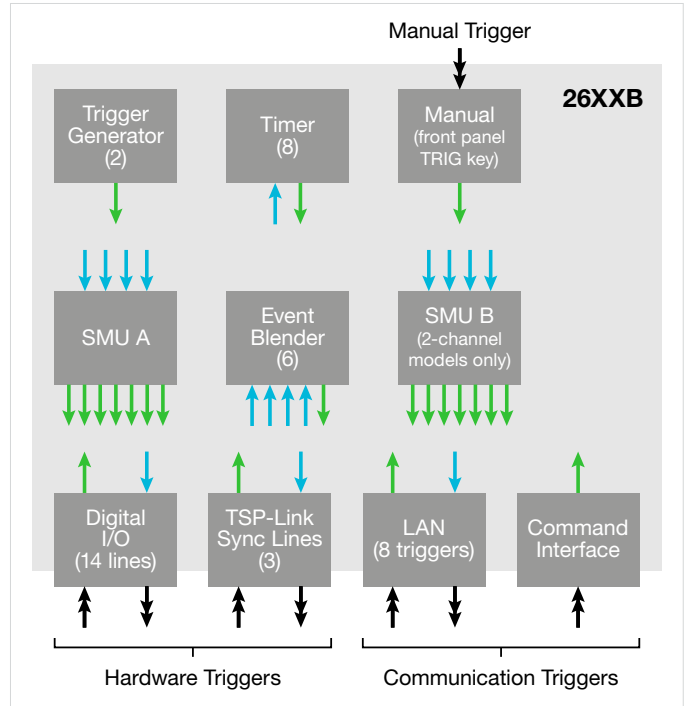


Figure 5. Keithley 2600B series SMU trigger overview.

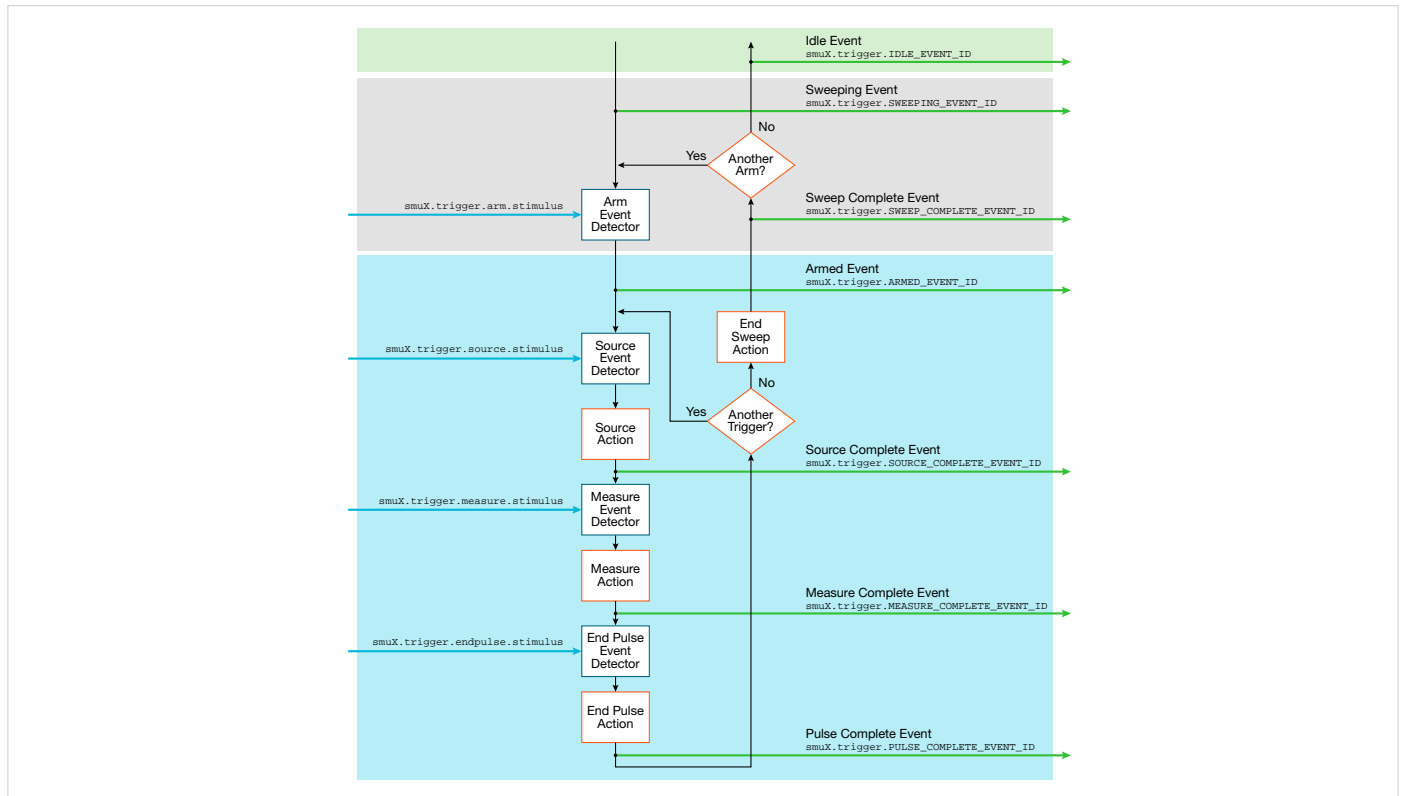


Figure 6. Keithley 2600B Series SMU flow chart for synchronous trigger model.

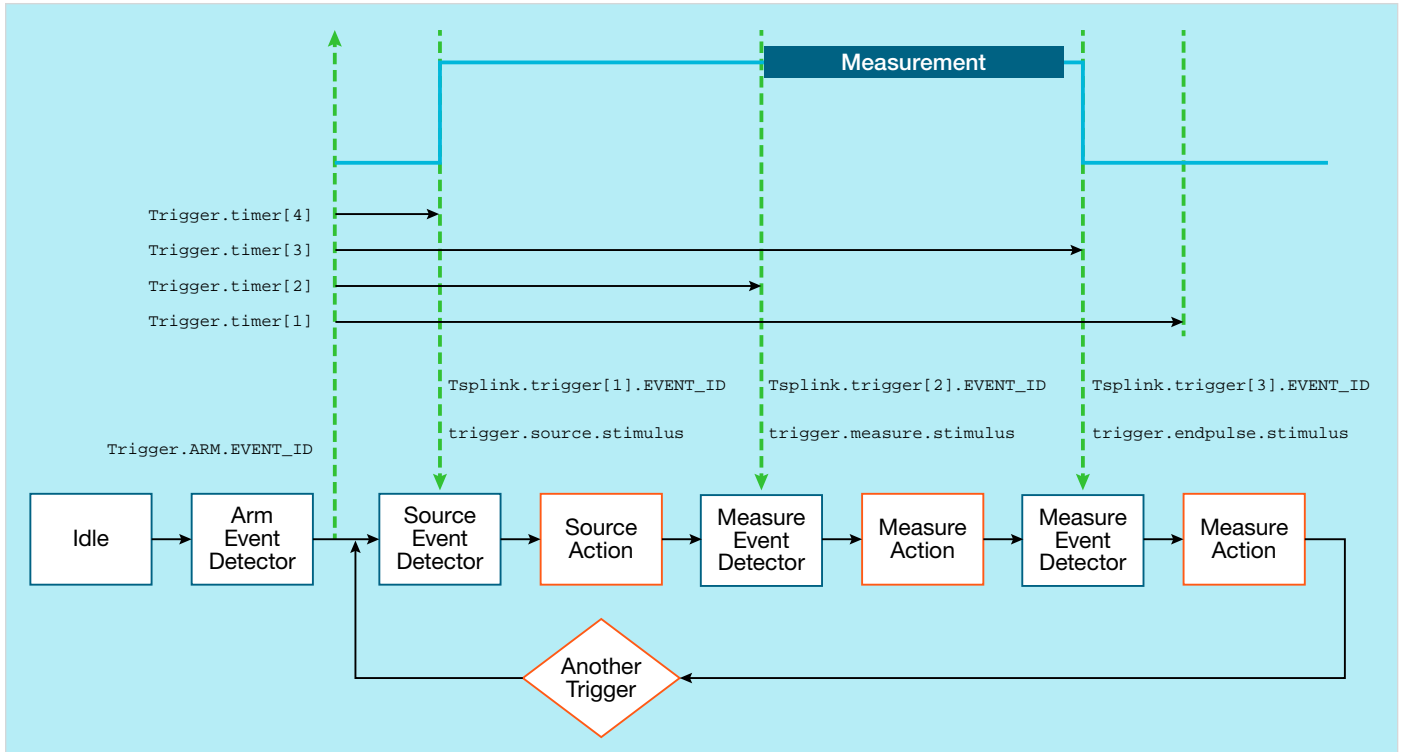


Figure 7. Keithley 2602B and 2606B trigger model implementation of the LIV sweep.

The TSP script depicts the trigger model shown in **Figure 7**.

```
-- Configure idle source
smua.source.output = smua.OUTPUT_OFF
smua.source.func = smua.OUTPUT_DCAMPS
smua.source.rangei = 123-3
smua.source.limiti = 1

-- Configure pulse
smua.trigger.source.listi({40e-3})
smua.trigger.source.action = smua.ENABLE
smua.trigger.endpulse.action = smua.SOURCE_IDLE
smua.trigger.arm.count = 1
smua.trigger.arm.stimulus = 0
smua.trigger.count = pulse_count

-- Configure endpulse delay
trigger.timer[1].reset()
trigger.timer[1].delay = 5.67e-3
trigger.timer[1].count = 1
trigger.timer[1].stimulus = smua.trigger.SOURCE_COMPLETE_EVENT_ID
smua.trigger.endpulse.stimulus = trigger.timer[1].EVENT_ID
```

Trigger System in DMM7510

Keithley's DMM7510 is a TSP instrument that can be easily integrated with 2602B and 2606B SMUs via TSP-Link and maintains less than 1us synchronization across the entire system. The trigger interface on the DMM7510 is very similar to the 2602B and 2606B SMU's, which consists of eight trigger generators, four timers, one manual front panel key trigger, two even blender triggers, six hardware digital I/O triggers, three TSP-Link triggers, one Trigger Link VMC trigger, eight LAN triggers, a software command trigger and an analog trigger. See **Figure 8**.

The DMM7510 does not have a fixed trigger model like the one shown in **Figure 6** for the 2600B Series SMUs; however, it provides the user with the capability to create any trigger model for any test sequence. **Figure 9** shows a full list of the building blocks for constructing a trigger model, which includes looping, event detector (WAIT), measure (ACTION), delay (DELAY), etc.

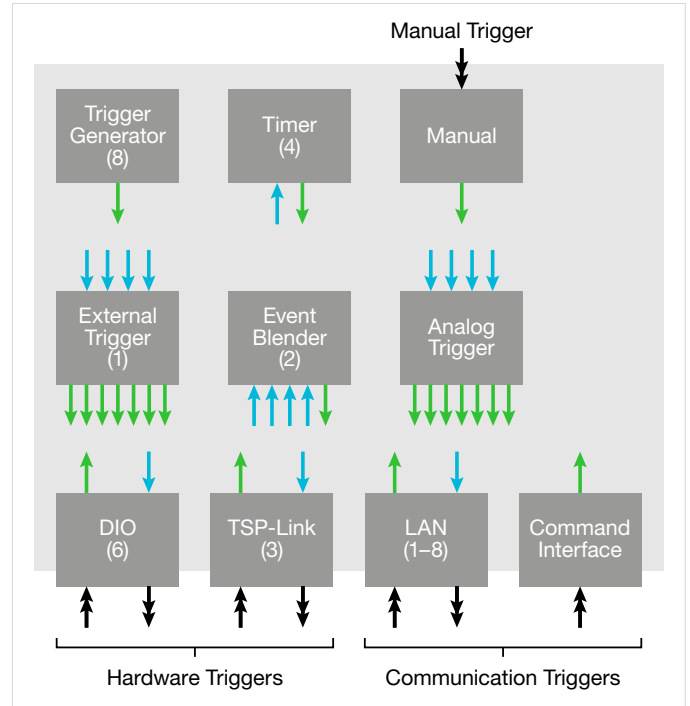


Figure 8. Keithley DMM7510 trigger overview.

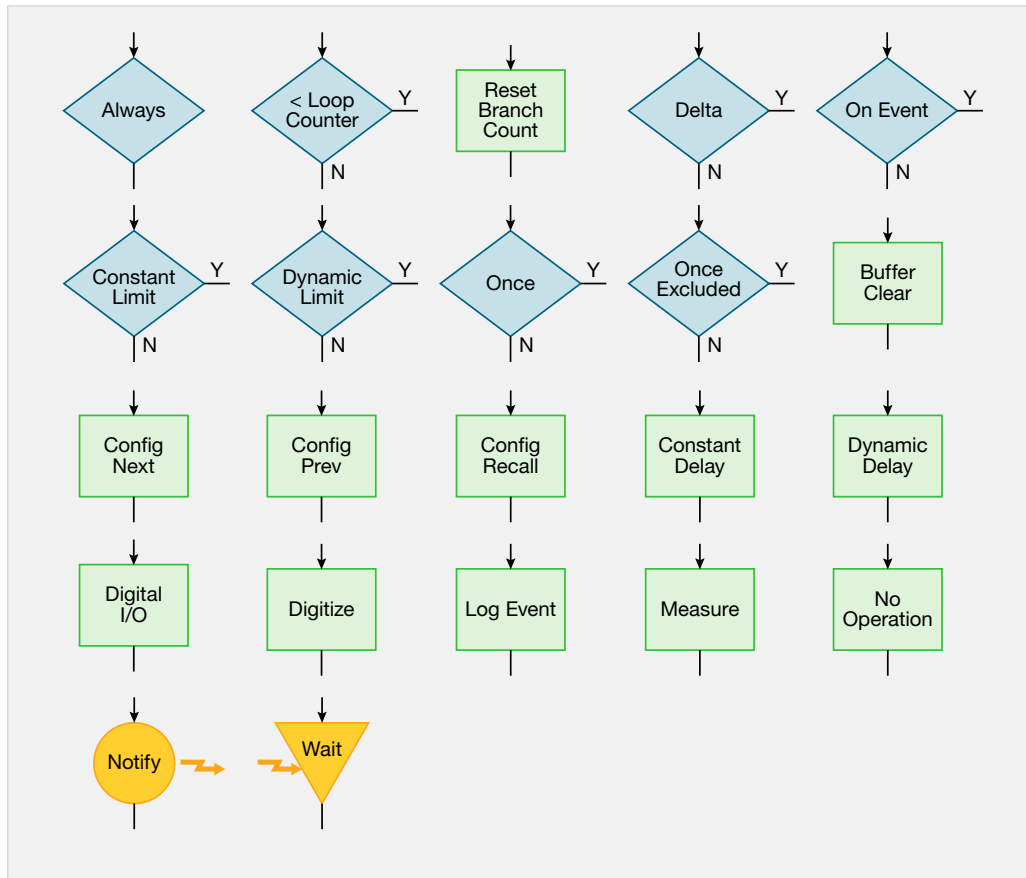


Figure 9. DMM7510 trigger flow building blocks.

The trigger model defined in the TSP script snippet is created for each DMM7510 in **Figure 3**. Each DMM7510 waits for the pulse start trigger from the corresponding SMU to initiate a measure action, whether it be a temperature or a photodiode current measurement. The temperature measurement is performed by integrating the resistance of the thermistor over the pulse width or the entire period for the pulse train.

The following TSP script snippet illustrates the trigger model created for performing temperature measurement synchronized through the timer object, LAN and digital I/O hardware triggers. The flow diagram corresponding to the trigger model is shown in **Figure 10**.

```
function NTC _ Test(NTCRange,MeasTime,MeasInterval,NPLC)
    MeasCounts = math.ceil(MeasTime/MeasInterval) + 1

    dmm.measure.range = NTCRange
    dmm.measure.nplc = NPLC

    trigger.timer[1].reset()
    trigger.timer[1].delay = MeasInterval
    trigger.timer[1].start.stimulus = trigger.EVENT _ NOTIFY1
    trigger.timer[1].start.generate = trigger.OFF
    trigger.timer[1].enable = trigger.ON

    trigger.model.setblock(1, trigger.BLOCK _ BUFFER _ CLEAR, defbuffer1)
    trigger.model.setblock(2, trigger.BLOCK _ WAIT, trigger.EVENT _ LAN5)
    trigger.model.setblock(3, trigger.BLOCK _ NOTIFY, trigger.EVENT _ NOTIFY1)
    trigger.model.setblock(4, trigger.BLOCK _ MEASURE, defbuffer1)
    trigger.model.setblock(5, trigger.BLOCK _ WAIT, trigger.EVENT _ TIMER1)
    trigger.model.setblock(6, trigger.BLOCK _ BRANCH _ COUNTER, MeasCounts, 3)

    trigger.model.initiate()
    trigger.lanout[5].protocol = lan.PROTOCOL _ MULTICAST
    trigger.lanout[5].connect()
    trigger.lanout[5].assert()
    waitcomplete()
    printbuffer(1,defbuffer1.n,defbuffer1)
end
```

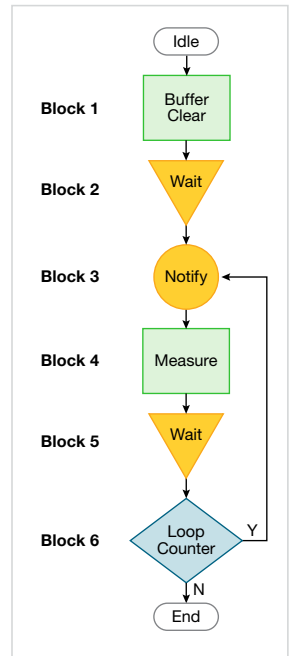


Figure 10. Trigger model.

Digitizing Current and Voltage in a Graphical DMM

In addition to integrating resistance, DMM7510 has a digitizing mode that allows capturing current or voltage at one mega-sample per second (1MS/s) the instrument’s full operating range. For example, it can digitize, at a 1 μs sample rate, current from 100 fA to 10 A with 18-bit resolution. Because test time is the most critical factor in a production environment, the ability to define the window of measurement precisely down to 1 μs resolution simply by changing the

sample count is extremely beneficial. The DMM7510 also automatically updates the average value of all the readings in the reading buffer. This further simplifies the data processing required from the measurement taken at the pulse top. You can extract the buffer average value and clear the buffer for the next pulse.

Figure 11 shows a series of current pulses captured by the DMM7510 in the current digitizing mode. The multi-touch touchscreen even allows zooming into each pulse with the touch of a fingertip.

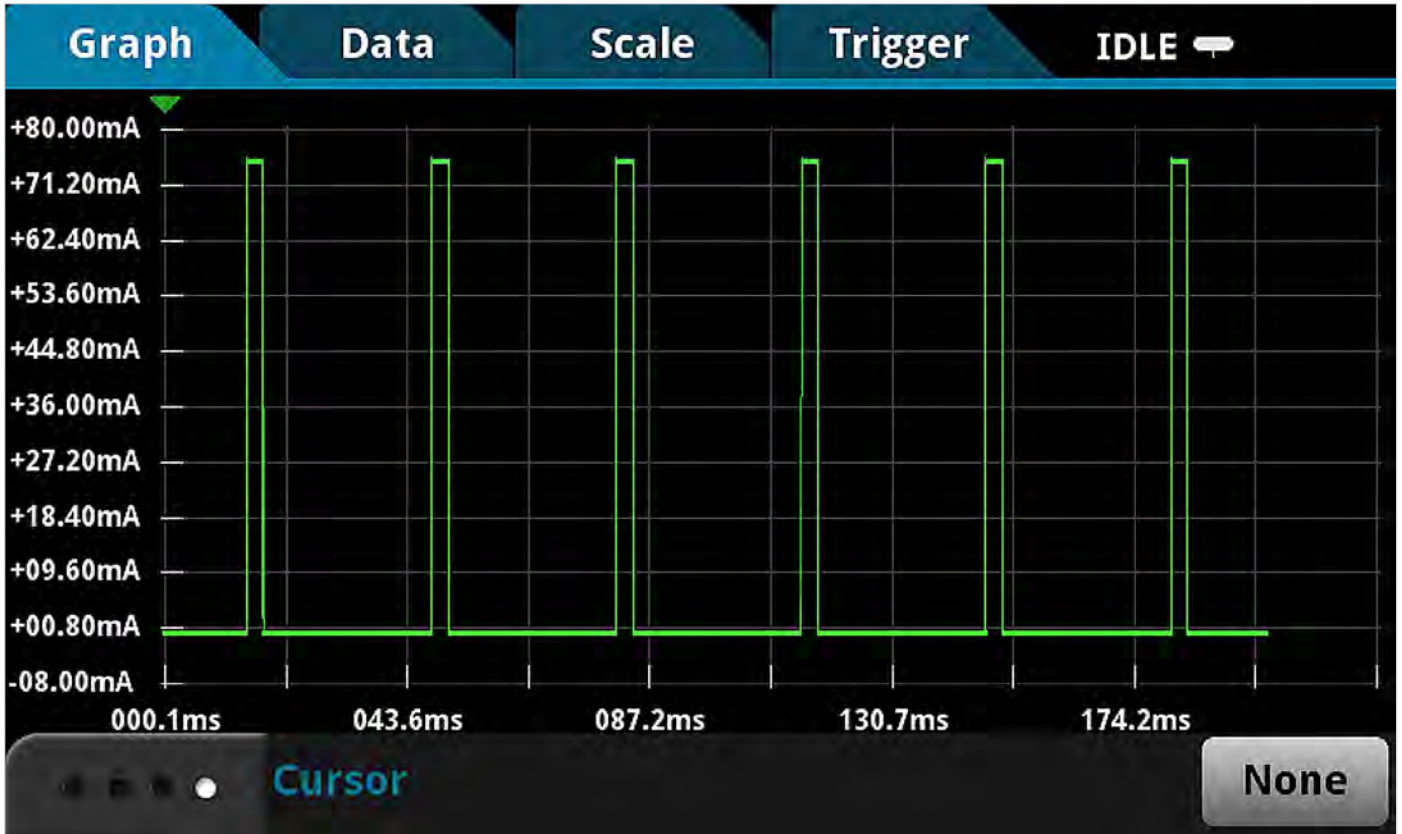


Figure 11. Pulse measurement in digitizing mode.

Conclusion

Keithley's TSP-enabled 2602B and 2606B SMUs and DMM7510 allow users to integrate bench instruments effortlessly into a holistic system and achieve industry's best trigger synchronization and maximum throughput for any

automated or production environment. Keithley's Test Script Processor and TSP-Link are two key technologies that enable more efficient and reliable electrical test for new applications such as 3D sensing.

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