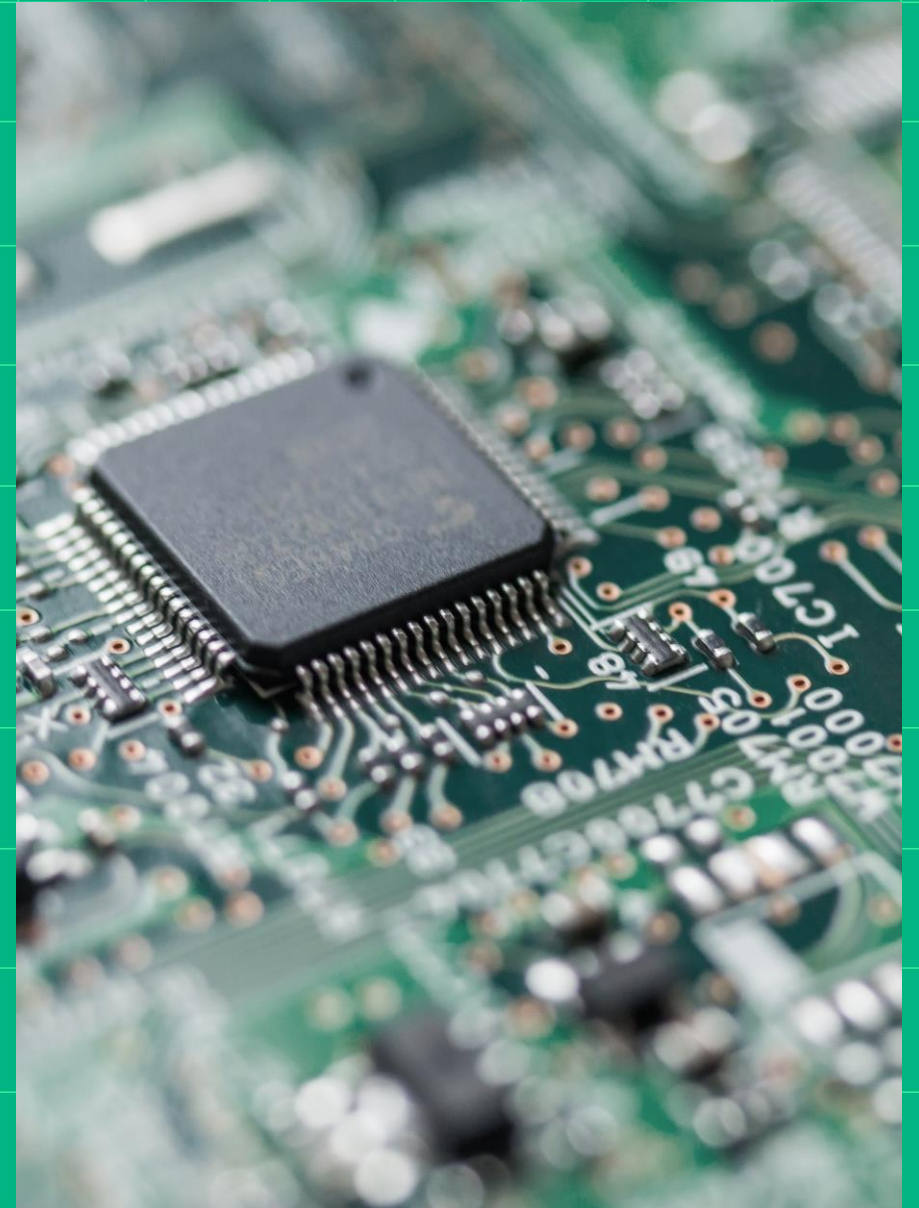


W  **LC**  **ME**  **AUST**  **N**

5 Tips for Optimizing NI SMUs for High Throughput Test

Craig Hitchman

Principal Applications Engineer





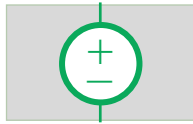
Optimizing Test Execution Is a Competitive Advantage

“Some ASIC manufacturers report that testing time consumes 40-50% of the entire IC product development cycle.”

IC Insights

McClean Report 2015

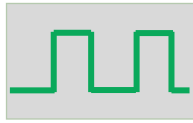
Functionality of Source Measure Units



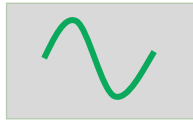
DC VOLTAGE SOURCE



DC CURRENT SOURCE



PULSE GENERATOR



WAVEFORM GENERATOR



VOLTMETER



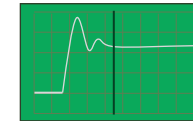
AMMETER



OHMMETER



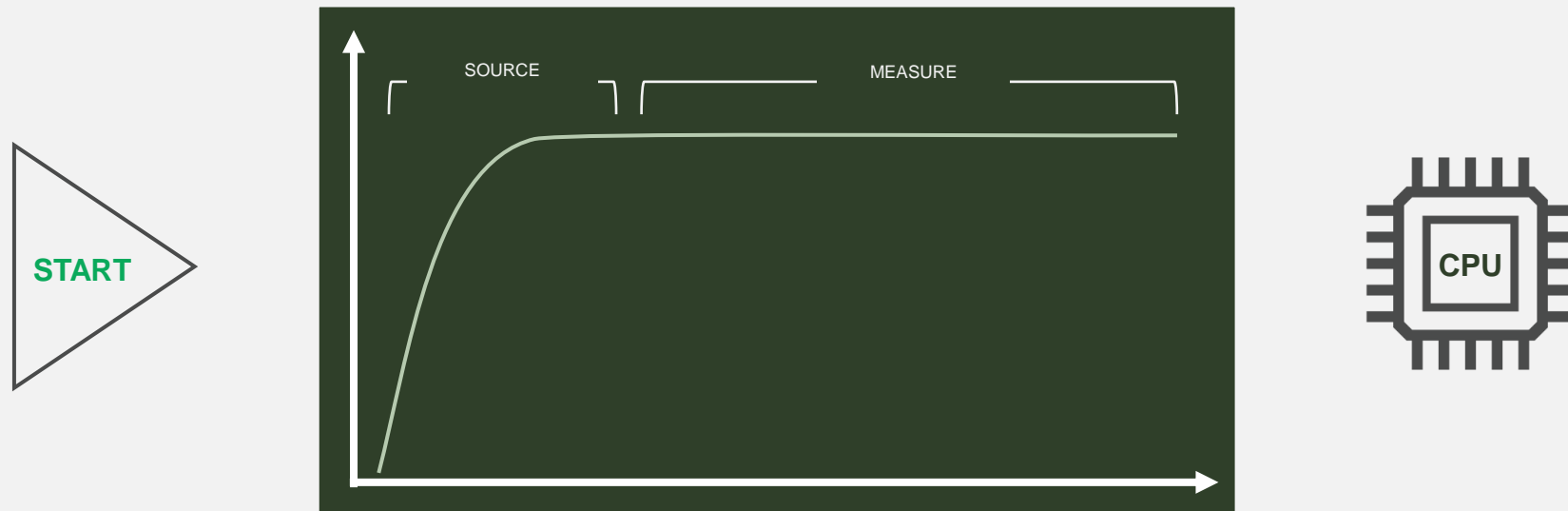
ISOLATED DIGITIZER



PROGRAMMABLE LOAD



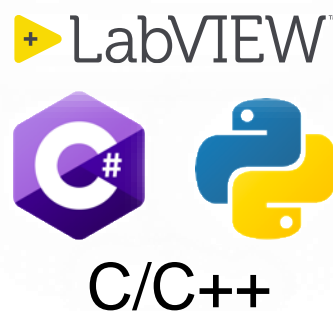
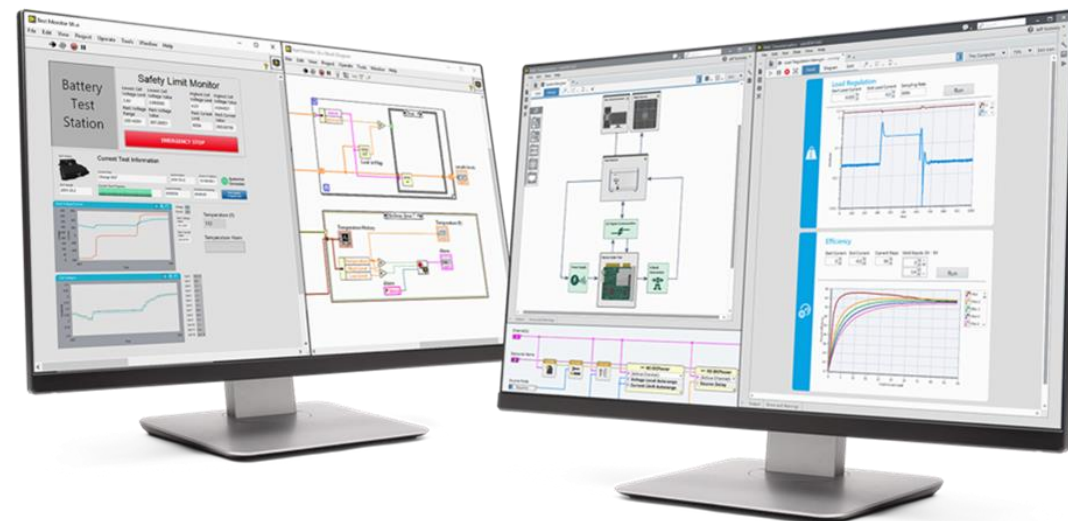
SMU Measurement Flow



You can take high-precision measurements quickly.
Removing small inefficiencies in timing can reduce your cost of test.

Programming Support

- NI product portfolio supports a breadth of programming languages: **LabVIEW**, **C/C++**, **C#**, **.NET**, **Python**
- **What you get with NI's best-in-class APIs:**
 - Well Documented API
 - Shipped Examples
 - Help Documentation
- NI ensures **long-term interoperability** of our instrumentation
 - NI instrument class driver APIs are consistent across all past & future product variants
 - Provides built in abstraction layer to prevent unnecessary code revisions when hardware is upgraded/replaced



```
import nidcpower
# Configure the session.

with nidcpower.Session(resource_name='PXI1Slot2', channels='0') as session:
    session.measure_record_length = 20
    session.measure_record_length_is_finite = True
    session.measure_when = nidcpower.MeasureWhen.AUTOMATICALLY_AFTER_SOURCE_COMPLETE
    session.voltage_level = 5.0

    session.commit()
    print('Effective measurement rate: {0} S/s'.format(session.measure_record_delta_time / 1))

samples_acquired = 0
print(' # Voltage Current In Compliance')
row_format = '{0:3d}: {1:8.6f} {2:8.6f} {3}'
with session.initiate():
    while samples_acquired < 20:
        measurements = session.fetch_multiple(count=session.fetch_backlog)
        samples_acquired += len(measurements)
        for i in range(len(measurements)):
            print(row_format.format(i, measurements[i].voltage, measurements[i].current, measuremen
```


Instrument Studio™

Application Software for Interactive Instrument Control and Lab Measurements

All your instruments in a single application

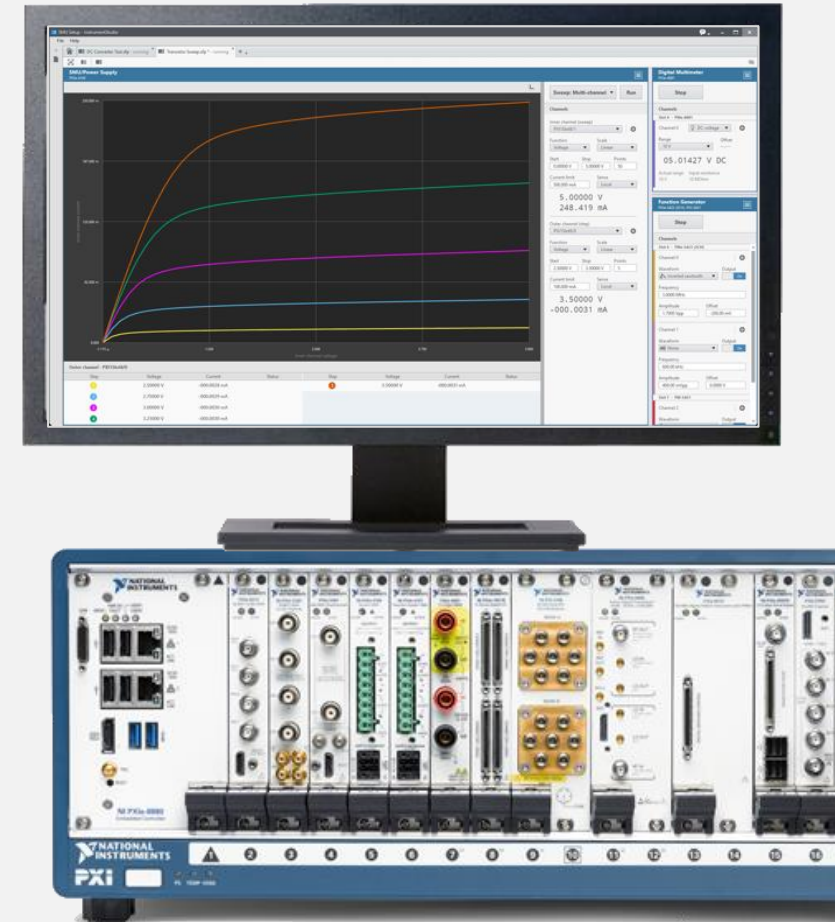
Capture screenshots and export data

Build custom plugins for common measurements or tasks

Share projects with colleagues and between systems

Export configurations for programmatic use

Monitor and debug automated test systems



System SMU Family



PXIe-	4135	4136	4137	4138	4139	4190 LCR
Max Source Power	20W/40W	20W	20W/40W	20W	20W/40W	1W/4W
Max Sink Power	12W/40W	12W	12W/40W	12W	12W/40W	1W/4W
Max Sampling	1.8 MS/s					600 kS/s
Max Update	100 kS/s					
Max Voltage	200 V			60 V		10V/40V
Max DC Current	1 A			3 A		100mA
Max Pulsed Current	3 A	n/a	3 A	n/a	10 A	n/a
Current Sensitivity	10 fA	1 pA	100 fA	1 pA	100 fA	1 fA
SourceAdapt	Yes	No	Yes	No	Yes	Yes
Connectivity	Triaxial	Screw Terminals				BNC

Multi Channel SMU Family



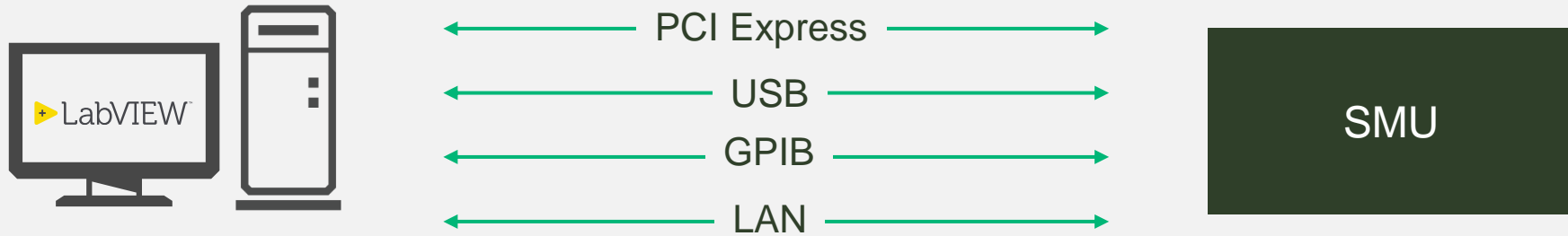
PXIe-	4140/4141	4142/4143	4144/4145	4147	4162	4163
Channels	4			12		24
Max Sampling	600 kS/s			1.8 MS/s	100 kS/s	
Max Update	100 kS/s					
Max Voltage	10 V	24 V	6 V	8 V	24 V	24 V
Max DC Current	100 mA	150 mA	500 mA	3 A	100 mA	50 mA
Current Sensitivity	100pA/10pA	100pA/10pA	150pA/15pA	100 fA	10pA/100pA	10pA/100pA
SourceAdapt	No/Yes	No/Yes	No/Yes	Yes	Yes	Yes

The 5 Tips



- 1 Choose the right equipment**
- 2 Measure in parallel
- 3 Optimize source delay and aperture time
- 4 Utilize advanced instrument capabilities
- 5 Tune transient response with Source Adapt

1. Bus Communication

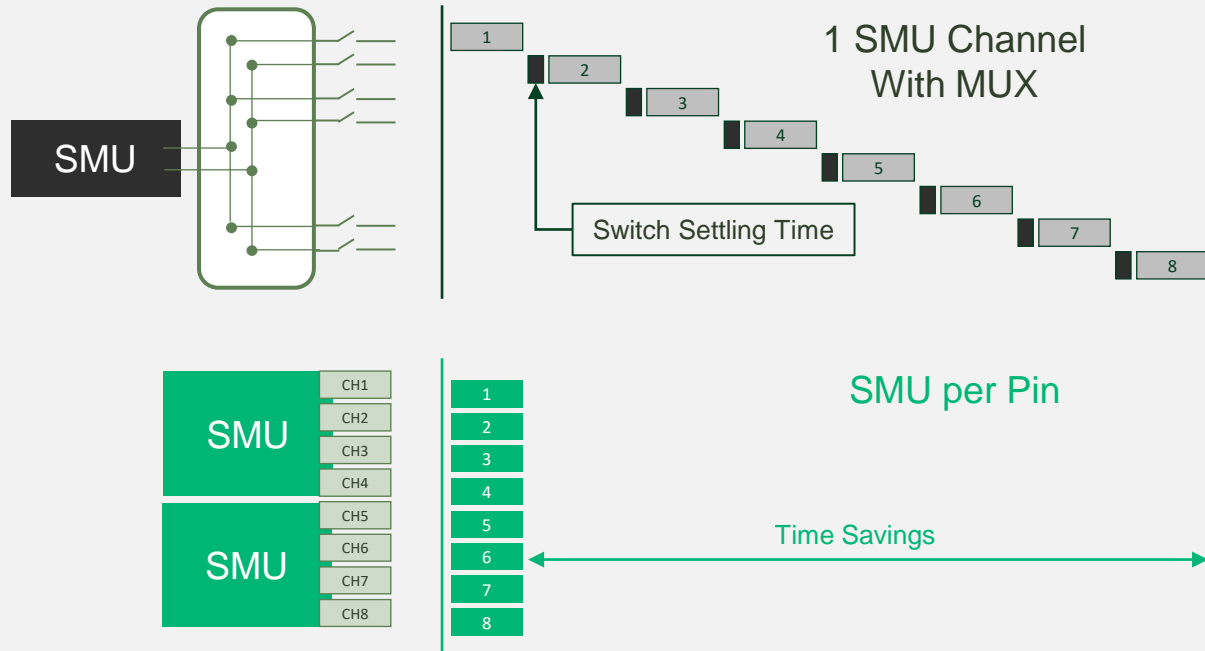




SMU Ranges

Model	SourceAdapt	Voltage Ranges (V)	Current Ranges (A)	Channels
PXle-4135	Yes	±0.6, ±6, ±20, ±200	±10n, ±1u, ±100u, ±1m, ±10m, ±100m, ±1	1
PXle-4136	No	±0.6, ±6, ±20, ±200	±1u, ±10u, ±100u, ±1m, ±10m, ±100m, ±1	1
PXle-4137	Yes	±0.6, ±6, ±20, ±200	±1u, ±10u, ±100u, ±1m, ±10m, ±100m, ±1	1
PXle-4138	No	±0.6, ±6, ±60	±1u, ±10u, ±100u, ±1m, ±10m, ±100m, ±1, ±3	1
PXle-4139	Yes	±0.6, ±6, ±60	±1u, ±10u, ±100u, ±1m, ±10m, ±100m, ±1, ±3	1
PXle-4140	No	±10	±10u, ±100u, ±1m, ±10m, ±100m	4
PXle-4141	Yes	±10	±10u, ±100u, ±1m, ±10m, ±100m	4
PXle-4142	No	±24	±10u, ±100u, ±1m, ±10m, ±150m	4
PXle-4143	Yes	±24	±10u, ±100u, ±1m, ±10m, ±150m	4
PXle-4144	No	±6	±10u, ±100u, ±1m, ±10m, ±100m, ±500m	4
PXle-4145	Yes	±6	±10u, ±100u, ±1m, ±10m, ±100m, ±500m	4
PXle-4147	Yes	±1, ±8	±1u, ±10u, ±100u, ±1m, ±10m, ±100m, ±1, ±3	4
PXle-4162	Yes	±24	(±1u), ±10u, ±100u, ±1m, ±10m, ±100m	12
PXle-4163	Yes	±24	(±1u), ±10u, ±100u, ±1m, ±10m, ±50m	24
PXle-4190	Yes	±1, ±10, ±40	±1n, ±100n, ±1u, ±10u, ±100u, ±1m, ±10m, ±100m	1

Parallel Versus Serial SMU Channels



24-Channel SMUs

400+ channels in PXI chassis
Parallel execution in LabVIEW and TestStand

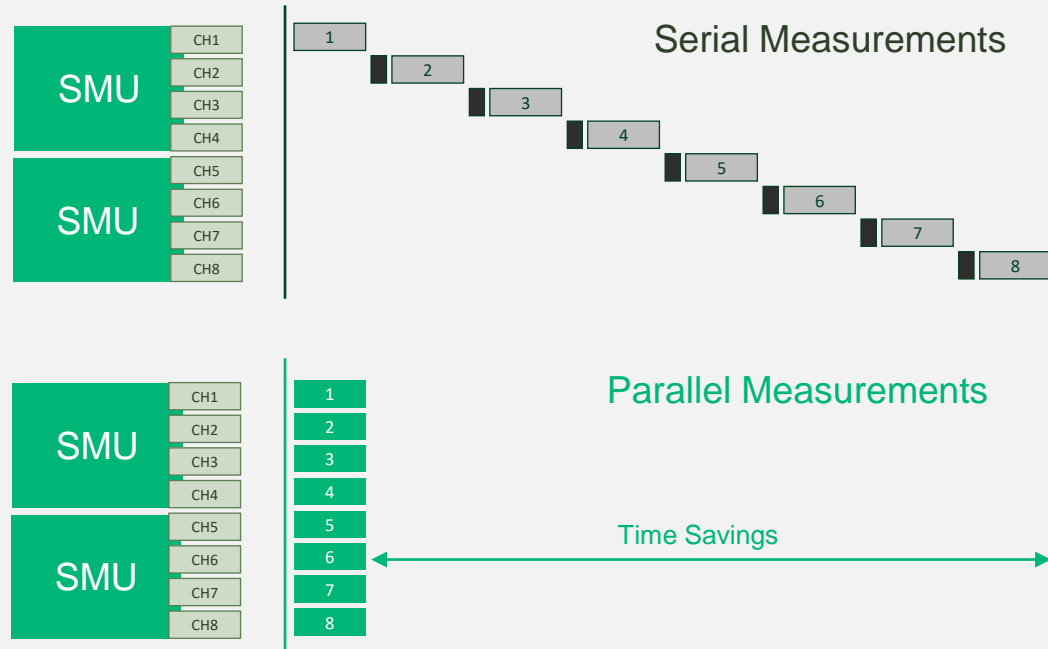
The 5 Tips



- 1 Choose the right equipment
- 2 Measure in parallel**
- 3 Optimize source delay and aperture time
- 4 Utilize advanced instrument capabilities
- 5 Tune transient response with Source Adapt

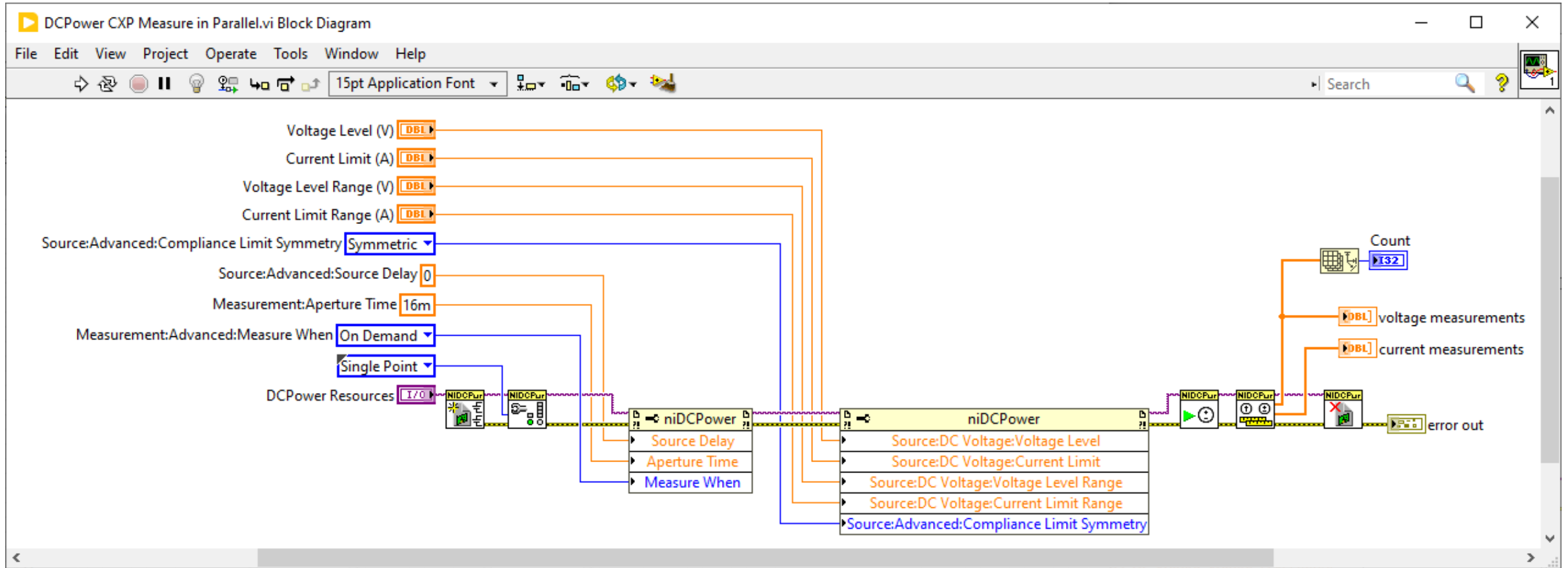


Parallel Versus Serial Measurements





DCPower Parallel Measurements





DCPower Parallel Measurements

DCPower Resources
SMU_4145_C3_S04/0-3, SMU_4143_C3_S03/0-3, SMU_4141_C3_S02/0-3

Voltage Level (V)
500m

Current Limit (A)
1m

Voltage Level Range (V)
1

Current Limit Range (A)
10m

Count
12

voltage measurements

500m
499.999m
500m
499.998m
500.001m
500m
499.997m
500.002m
219.729m
499.999m
499.999m
500.002m
0

current measurements

-66.2974n
-123.874n
-104.263n
-89.9737n
144.148n
135.89n
97.4648n
58.2516n
999.999u
2.47767u
90.1189u
40.1497n
0

error out

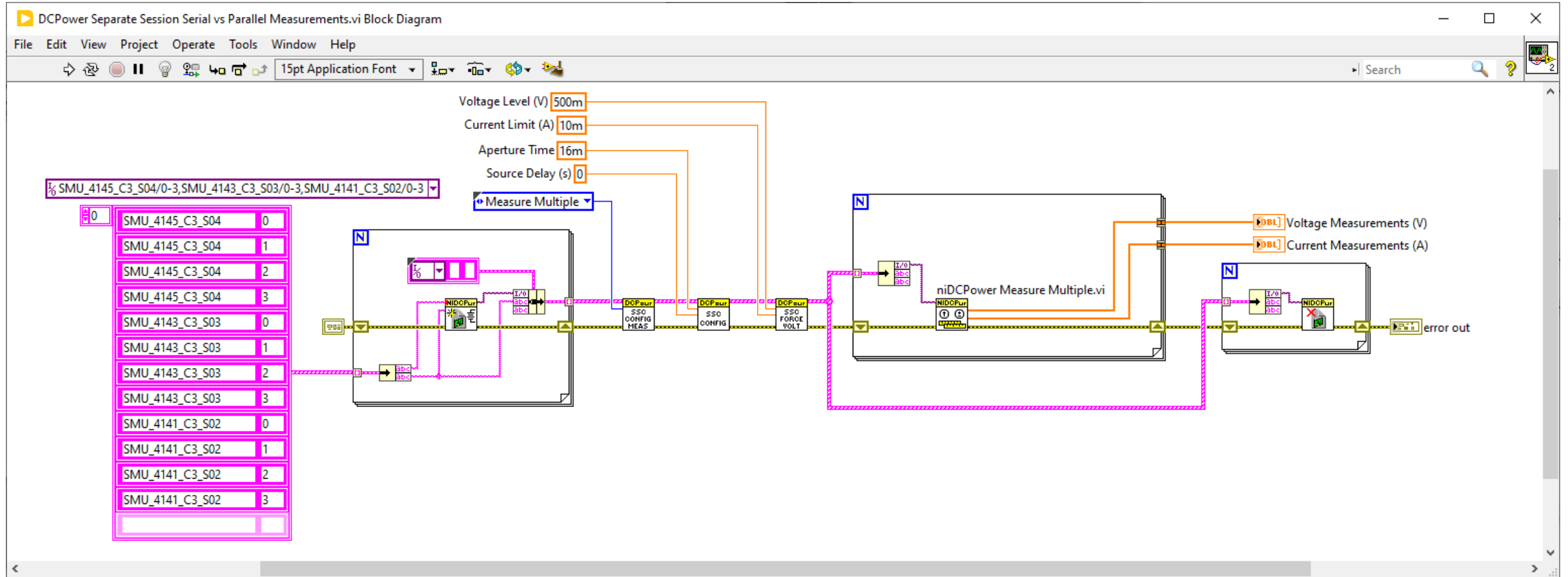
status	code
	d 0

source

SMU_4141_C3_S02/0-3
SMU_4143_C3_S03/0-3
SMU_4145_C3_S04/0-3
SMU_4145_C3_S04/0-3, SMU_4143_C3_S03/0-3, SMU_4141_C3_S02/0-3

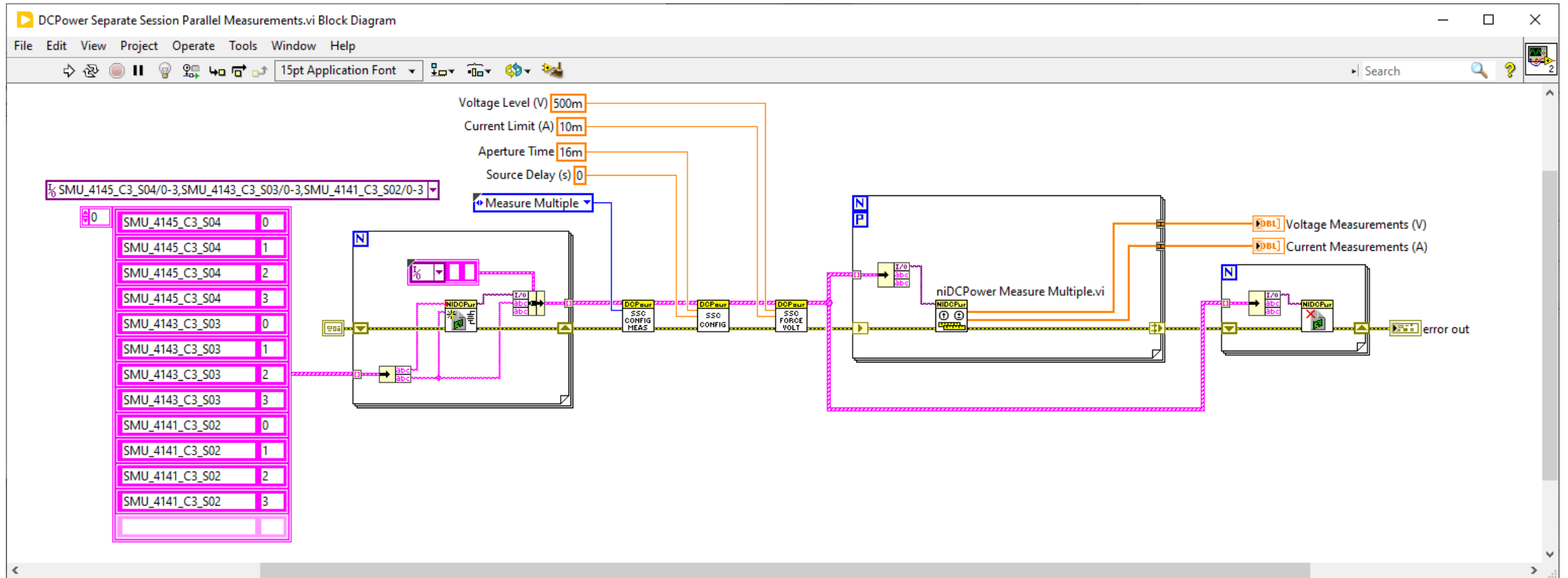


DCPower Separate Session Serial Measurements



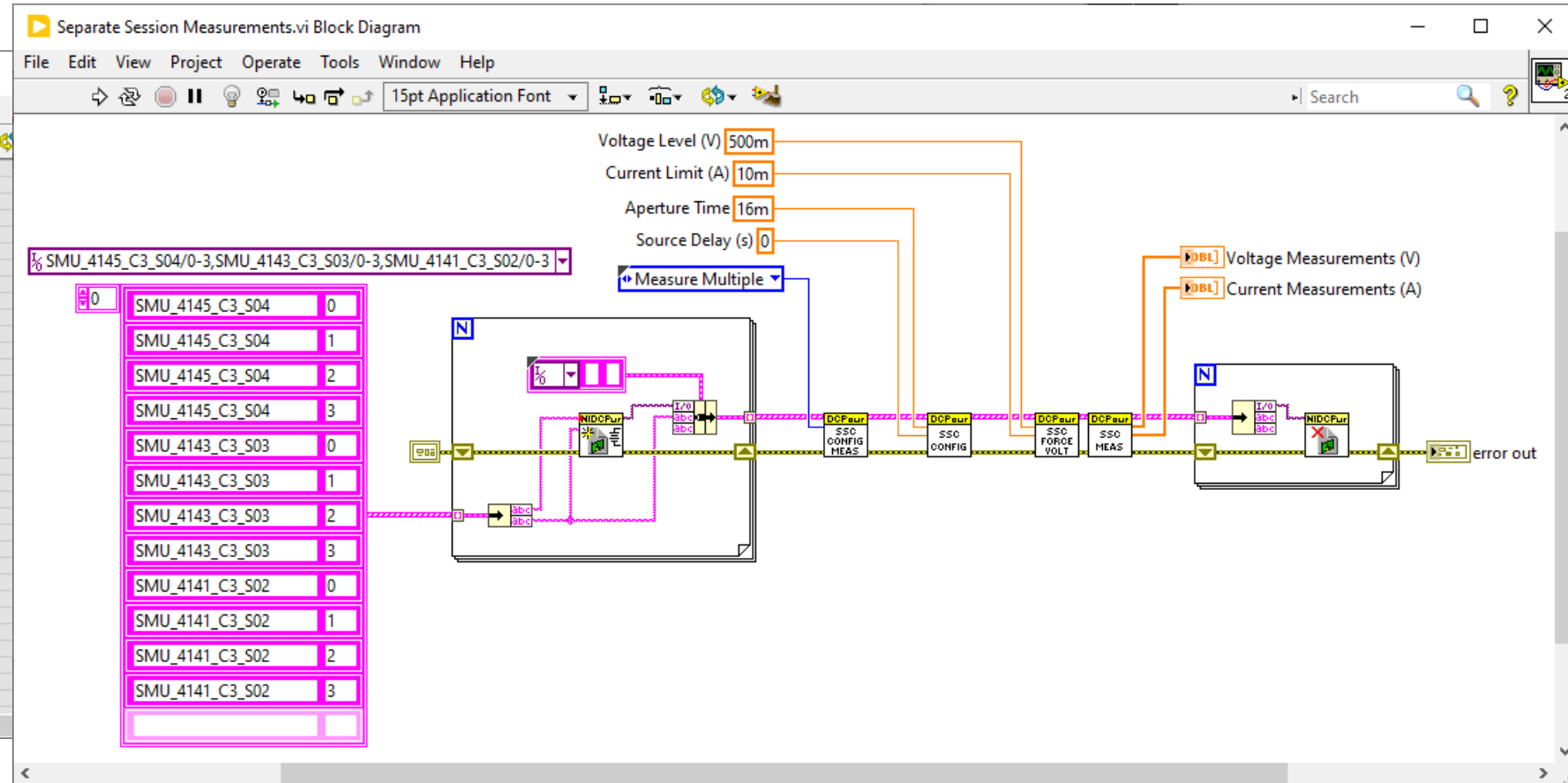
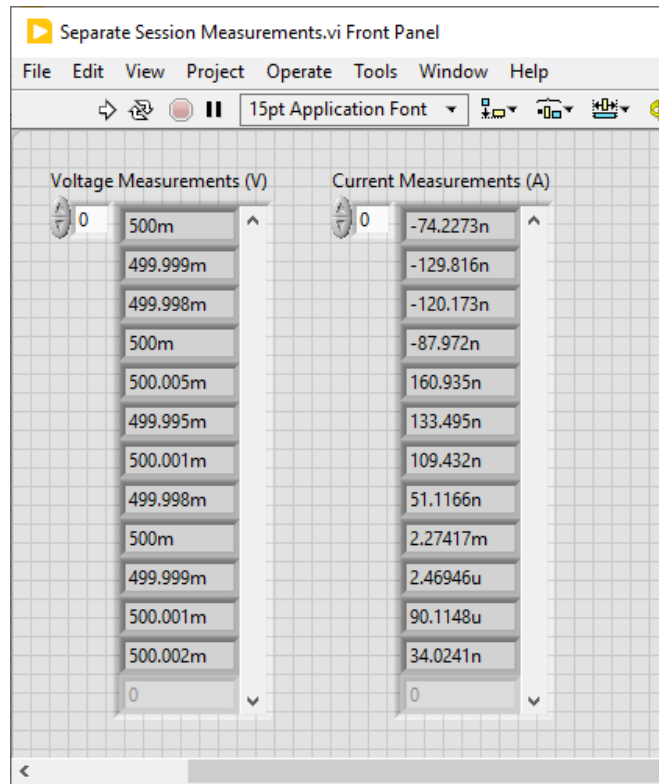


DCPower Separate Session Parallel Measurements





DCPower Separate Session Parallel Measurements



DCPower Separate Session Parallel Measurements in C#

```
public void Measure(out double[] voltageMeasurements, out double[] currentMeasurements)
{
    var vMeasurements = new double[SSC.Length];
    var iMeasurements = new double[SSC.Length];

    Parallel.ForEach(SSC, (ssc, state, index) =>
    {
        if (DevTools.UseSoftwareMeasureTriggers && ssc.InstrumentModel != 4110)
        {
            ssc.Session.Triggers.MeasureTrigger.SendSoftwareEdgeTrigger();
            var measurements = ssc.Session.Measurement.Fetch(ssc.DriverChannelList, PrecisionTimeSpan.FromSeconds(5), 1);
            vMeasurements[index] = measurements.VoltageMeasurements[0];
            iMeasurements[index] = measurements.CurrentMeasurements[0];
        }
        else
        {
            var measurements = ssc.Session.Measurement.Measure(ssc.DriverChannelList);
            vMeasurements[index] = measurements.VoltageMeasurements[0];
            iMeasurements[index] = measurements.CurrentMeasurements[0];
        }
    });

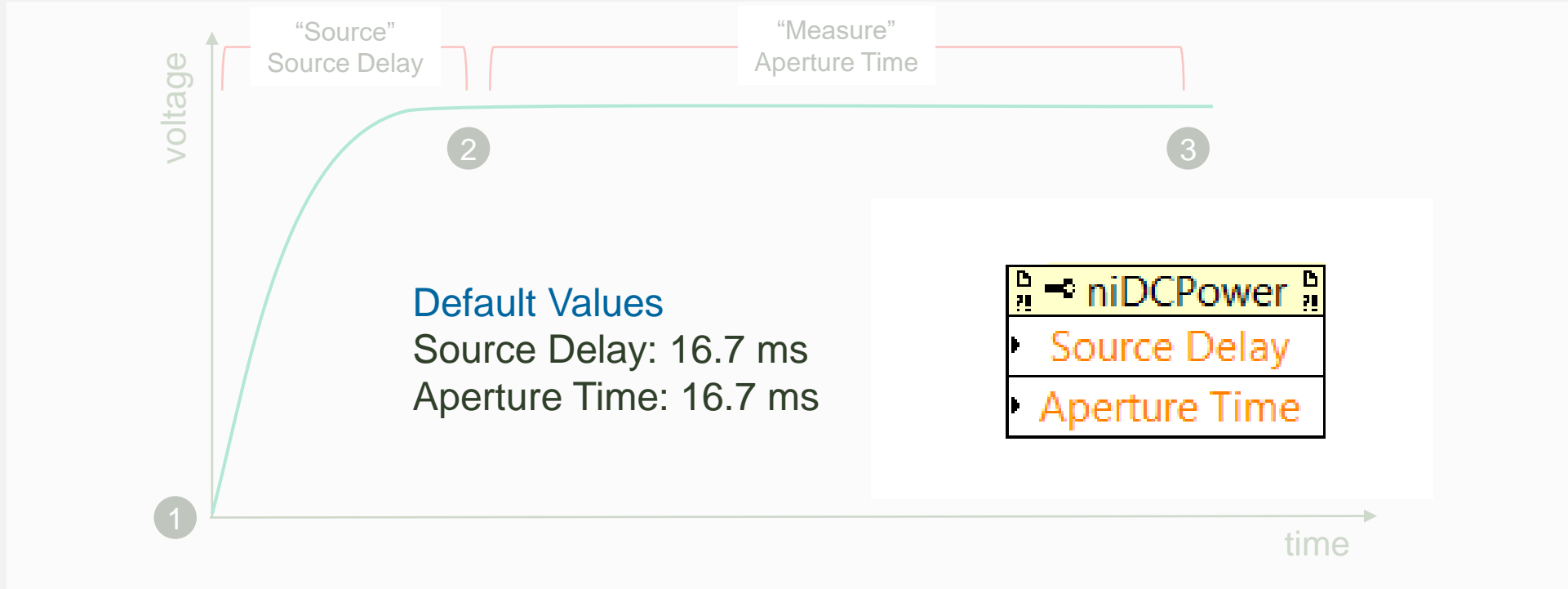
    voltageMeasurements = vMeasurements;
    currentMeasurements = iMeasurements;
}
```

The 5 Tips

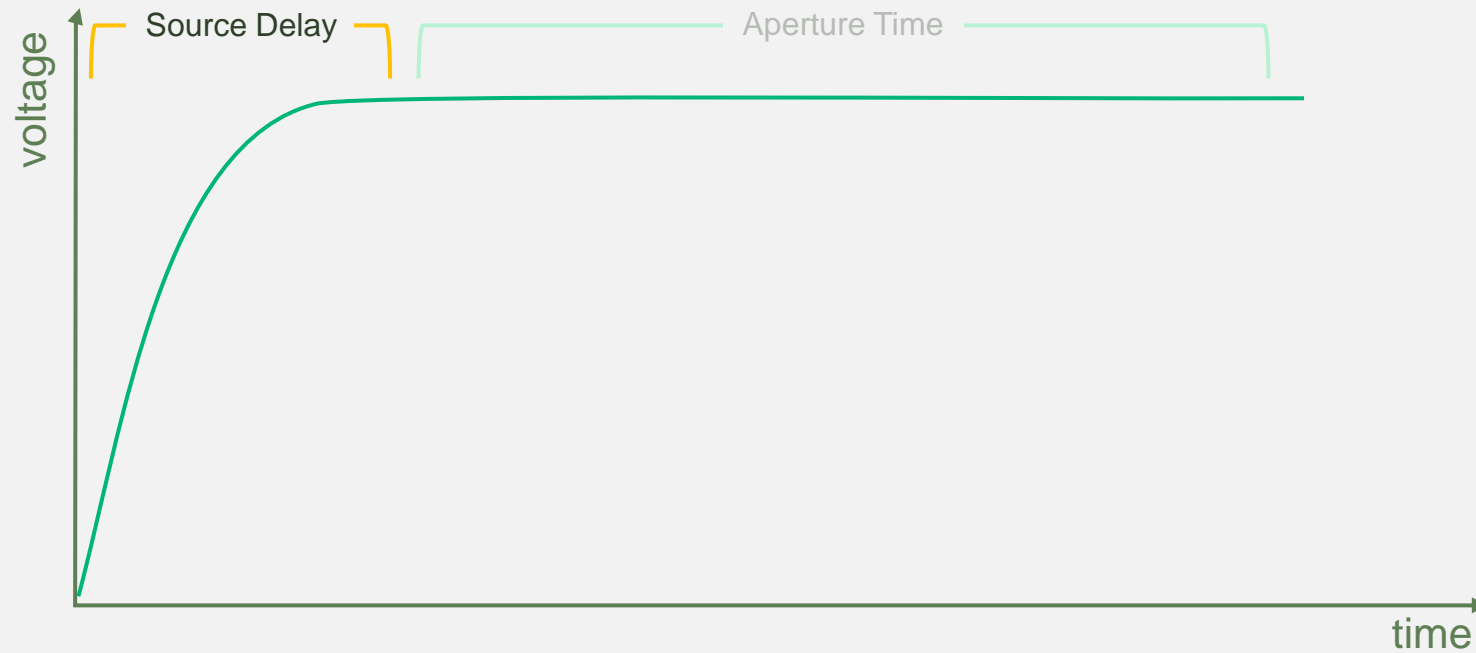


- 1 Choose the right equipment
- 2 Measure in parallel
- 3 Optimize source delay and aperture time**
- 4 Utilize advanced instrument capabilities
- 5 Tune transient response with Source Adapt

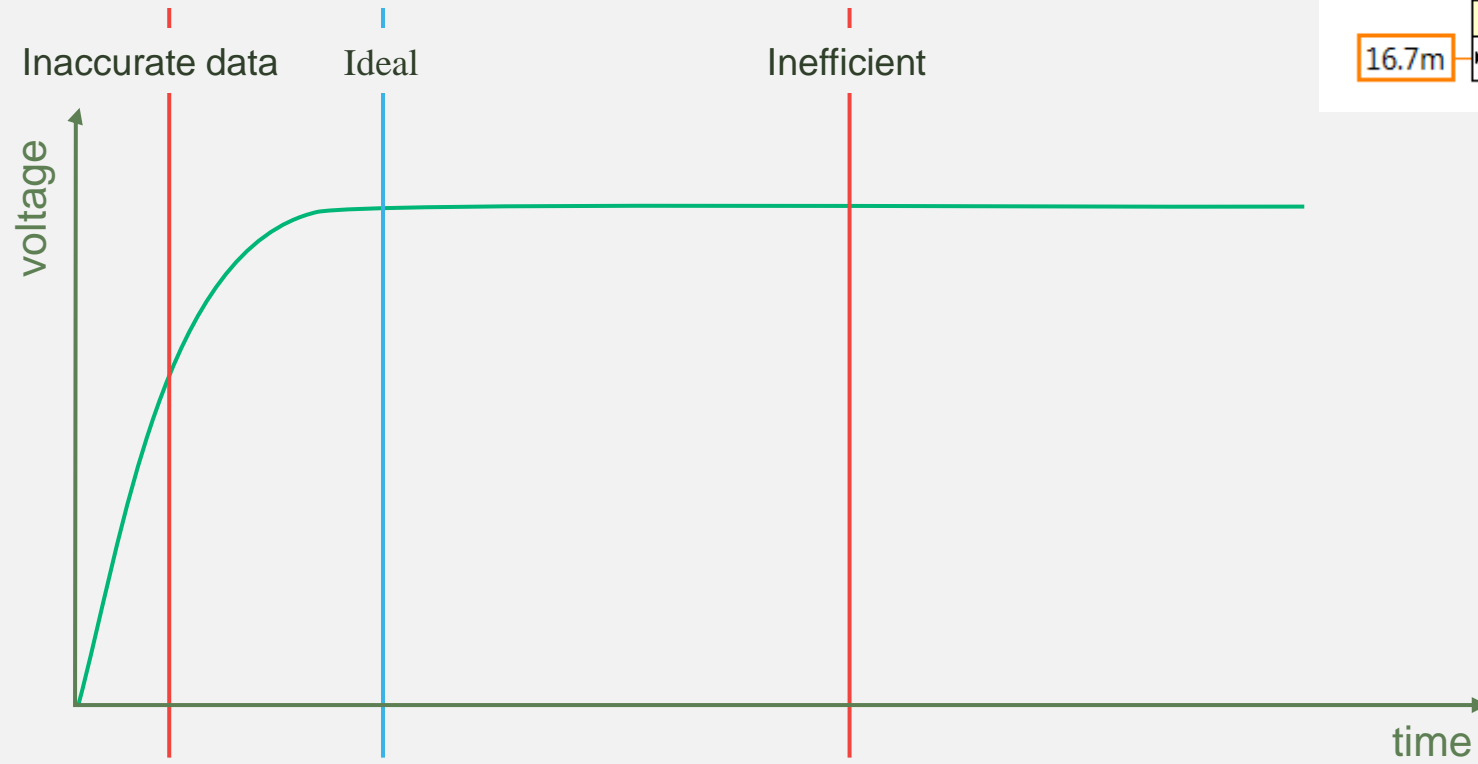
3. Source and Measure Cycle



Source and Measure Cycle



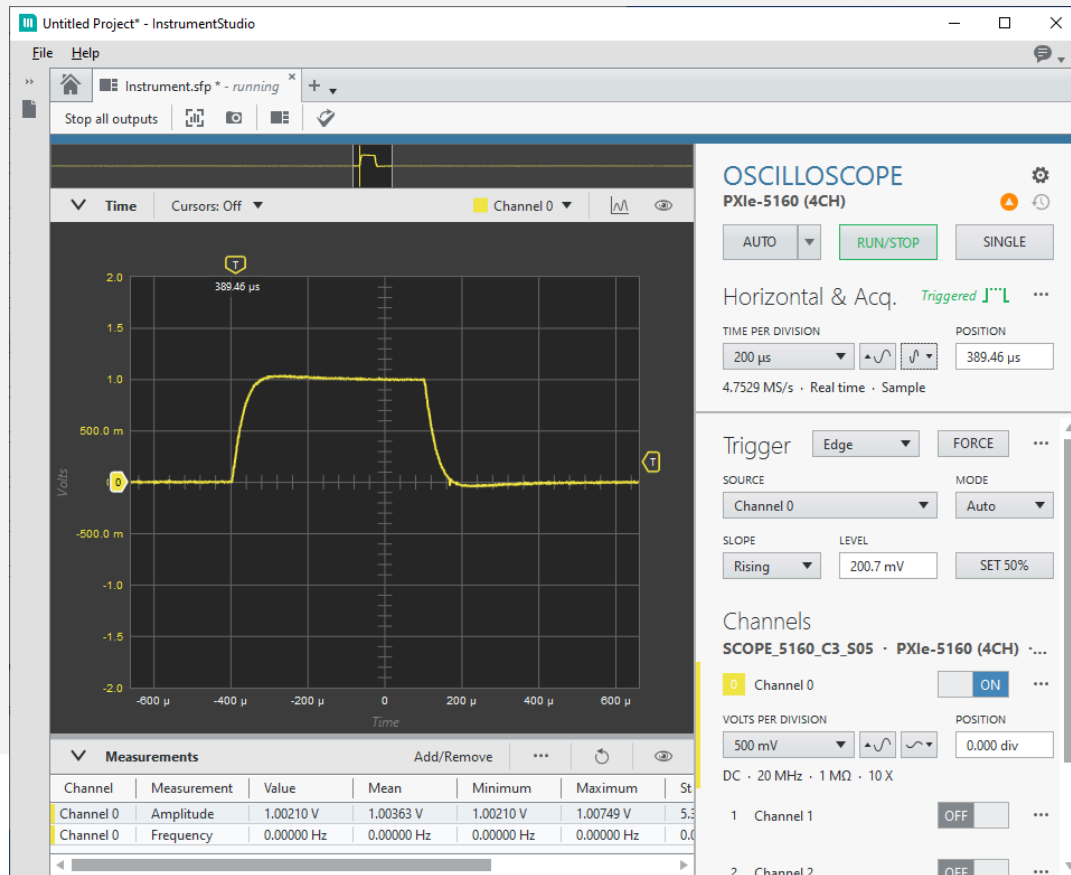
Source Delay



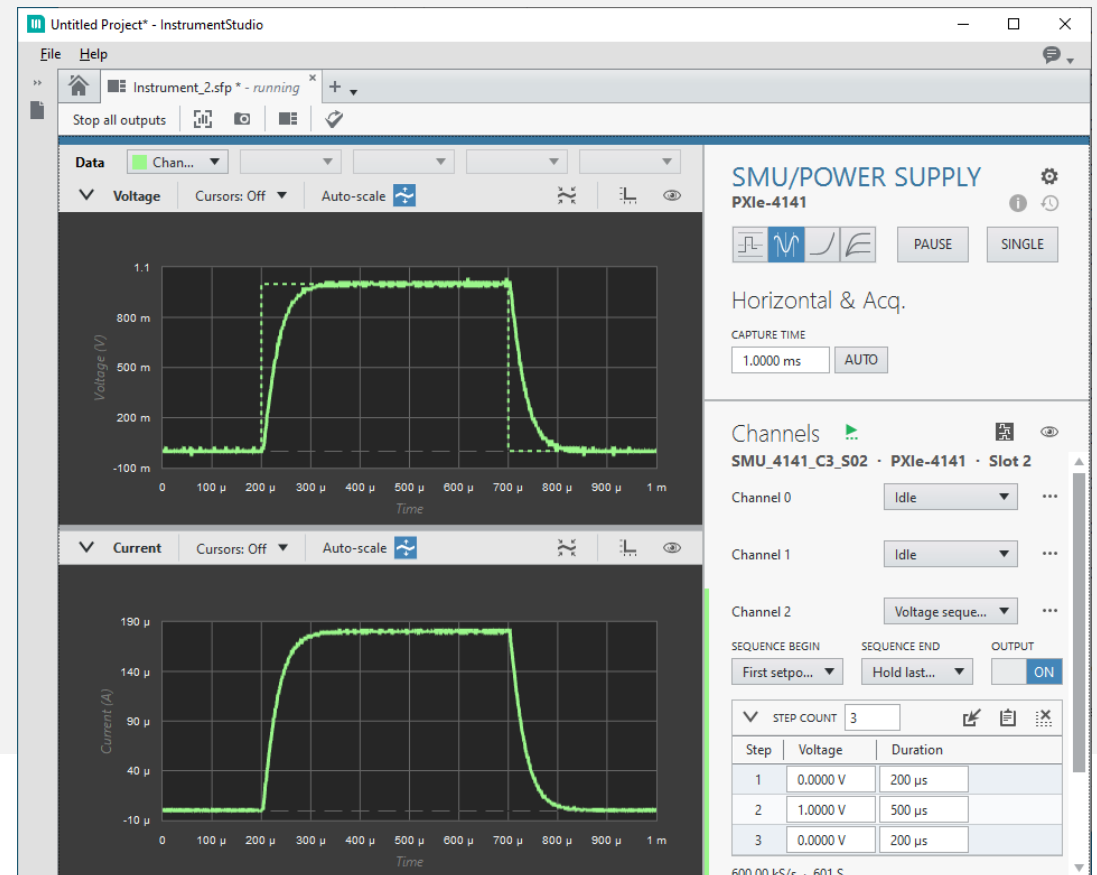
16.7m	niDCPower
	Source Delay

Determining Ideal Source Delay

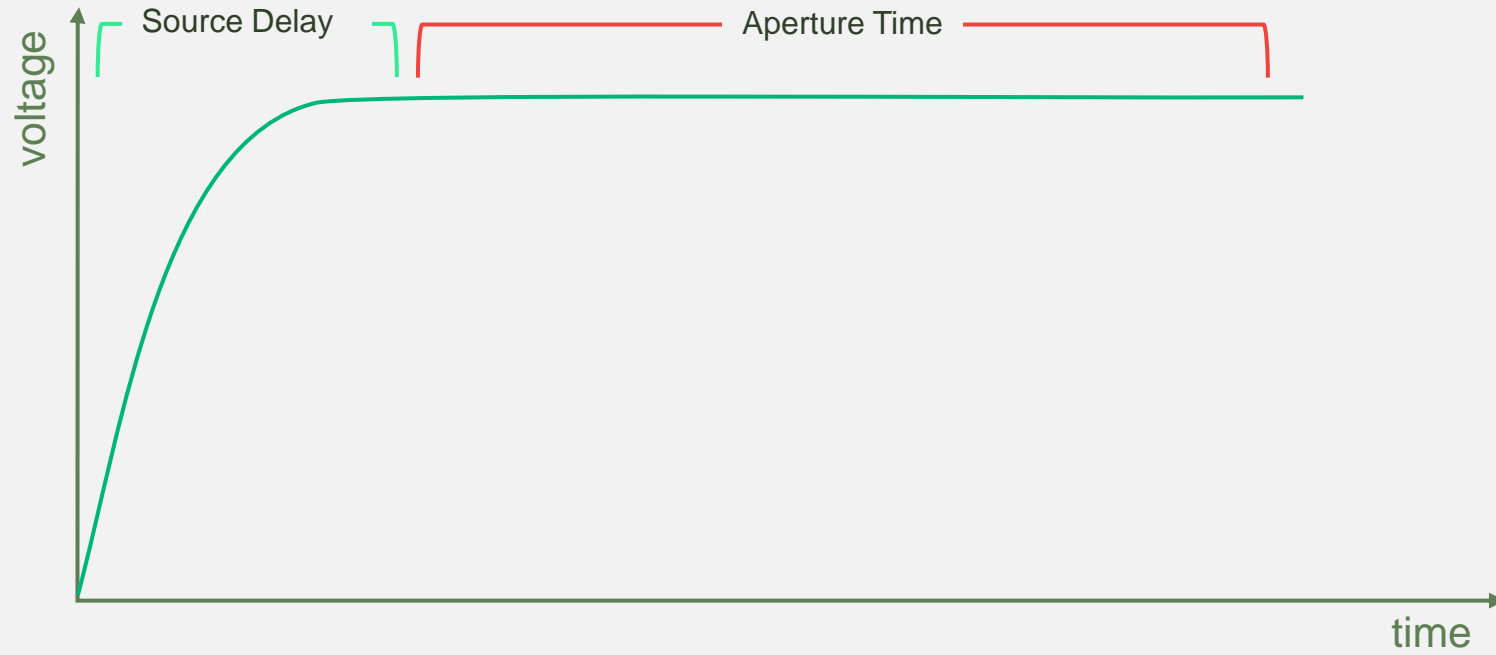
Method 1: Oscilloscope



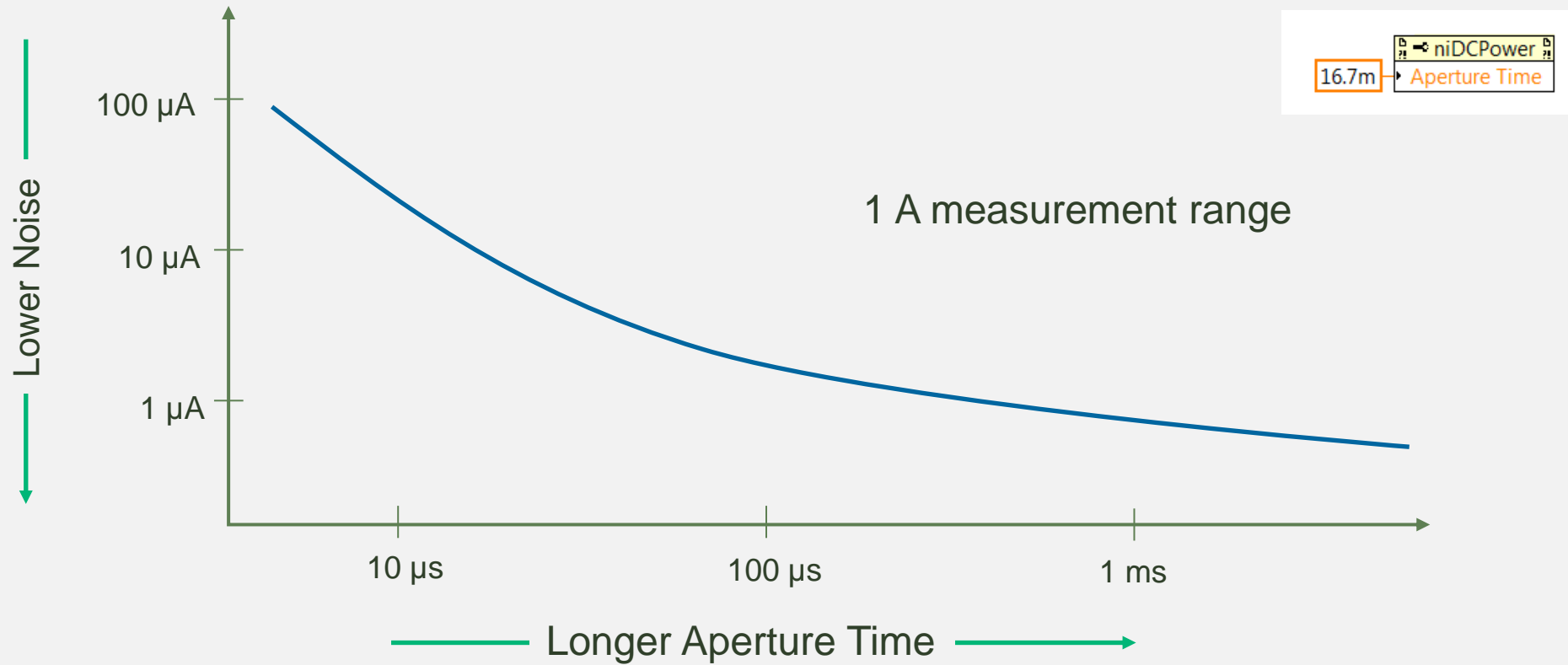
Method 2: SMU built-in digitizer



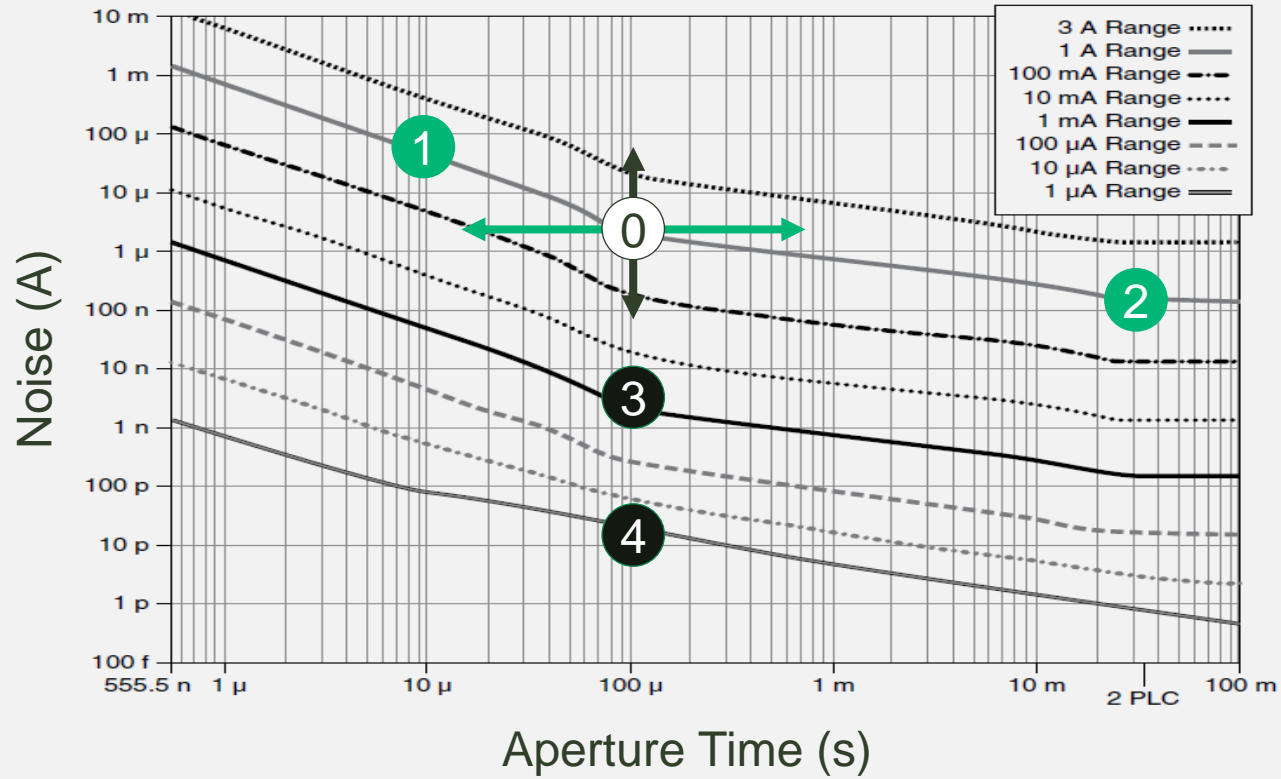
Source and Measure Cycle



Property: Aperture Time



Noise Versus Aperture Time



Noise	
0	1 μA
1	100 μA
2	100 nA
3	1 nA
4	10 pA

Noise Versus Aperture Time

The screenshot displays the NI Instrument Studio interface for a PXIe-4141 SMU/POWER SUPPLY. The main window shows two waveforms: Voltage (V) and Current (A), both plotted against Time. The Voltage waveform shows a step change from approximately -40 mV to 182.5 mV, with significant noise visible. The Current waveform shows a step change from 0 A to approximately 35 μ A, also with noise. The Channel Settings panel on the left shows the Aperture time mode set to Manual and the Aperture time set to 1.66667 μ s. The Channels panel on the right shows the SMU_4141_C3_S02 configuration with a sequence of three steps: 1) 0.0000 V for 200 μ s, 2) 200.00 mV for 500 μ s, and 3) 0.0000 V for 200 μ s.

Channel Settings

- Channel 0
- Channel 1
- Channel 2
- Channel 3

Compliance

- Limit symmetry: Symmetric
- Current limit: 100.000 μ A
- Current limit range: Auto

Timing

- Source delay: 0.00000 s
- Aperture time mode: Manual
- Aperture time unit: Seconds
- Aperture time: 1.66667 μ s

SourceAdapt tuning parameters

- Presets: Slow, Normal, **Fast**

SMU/POWER SUPPLY PXIe-4141

Horizontal & Acq. CAPTURE TIME: 1.0000 ms, AUTO

Channels

SMU_4141_C3_S02 · PXIe-4141 · Slot 2

- Channel 0: Idle
- Channel 1: Idle
- Channel 2: Voltage seque...

SEQUENCE BEGIN: First setpo... SEQUENCE END: Hold last... OUTPUT: ON

STEP COUNT: 3

Step	Voltage	Duration
1	0.0000 V	200 μ s
2	200.00 mV	500 μ s
3	0.0000 V	200 μ s

600.00 kS/s · 601 S

00.02742 V -000.1759 μ A -4.824 nW

Noise Versus Aperture Time

ScopeandSMUSequence - InstrumentStudio

File Help

Project Files

ScopeandSMUSequence.instudioproj

- Instrument.sfp *
- Instrument_2.sfp *

Channel Settings

Channel 0

Channel 1

Channel 2

Channel 3

Compliance

Limit symmetry: Symmetric

Current limit: 100.000 μ A

Current limit range: Auto

100 μ A

Timing

Source delay: 0.00000 s

Aperture time mode: Manual

Aperture time unit: Seconds

Aperture time: 10.0000 μ s

SourceAdapt tuning parameters

Presets: Slow Normal **Fast**

00.00154 V -000.0462 μ A -71.23 pW

Instrument.sfp * - running

Instrument_2.sfp * - running

Stop all outputs

Data Voltage Cursors: Off Auto-scale

210 m

155 m

100 m

45 m

-10 m

0 100 μ 200 μ 300 μ 400 μ 600 μ 800 μ 900 μ 1 m

Time

Current Cursors: Off Auto-scale

40 μ

27.5 μ

15 μ

2.5 μ

-10 μ

0 100 μ 200 μ 300 μ 400 μ 600 μ 800 μ 900 μ 1 m

Time

SMU/POWER SUPPLY

PXle-4141

PAUSE SINGLE

Horizontal & Acq.

CAPTURE TIME

1.0000 ms AUTO

Channels

SMU_4141_C3_S02 · PXle-4141 · Slot 2

Channel 0: Idle

Channel 1: Idle

Channel 2: Voltage seque...

SEQUENCE BEGIN: First setpo...

SEQUENCE END: Hold last...

OUTPUT: ON

STEP COUNT: 3

Step	Voltage	Duration
1	0.0000 V	200 μ s
2	200.00 mV	500 μ s
3	0.0000 V	200 μ s

100.00 kS/s · 101 S

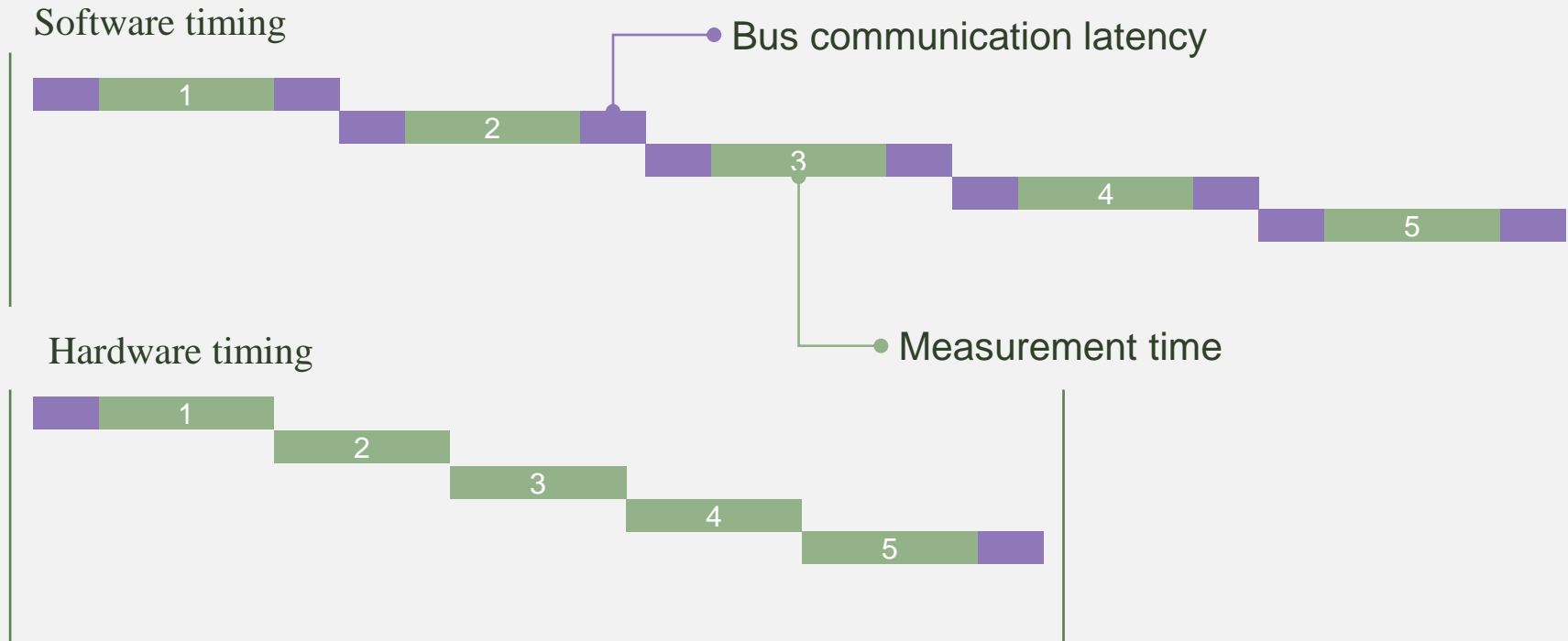
00.00154 V -000.0462 μ A

The 5 Tips

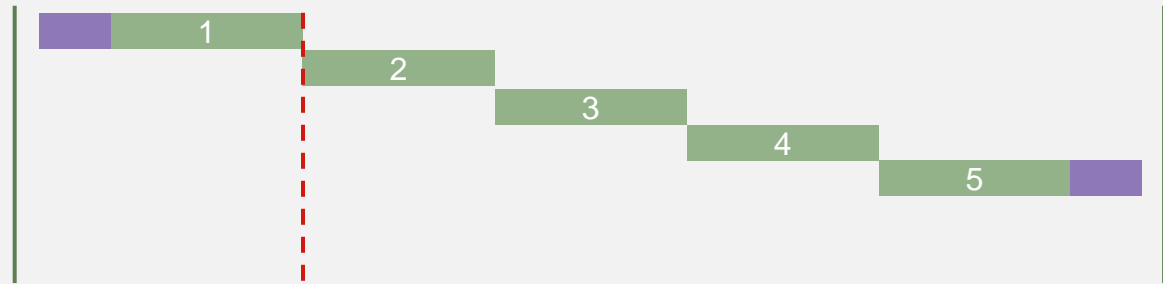


- 1 Choose the right equipment
- 2 Measure in parallel
- 3 Optimize source delay and aperture time
- 4 Utilize advanced instrument capabilities**
- 5 Tune transient response with Source Adapt

Sequencing: Software Versus Hardware Timing



Hardware-Timed Sequencing



• Reconfigure

- Output level
- Source delay

} “basic” sequence

- Aperture time
- Measurement range
- Compliance limit
- Output mode (I or V)
- ...

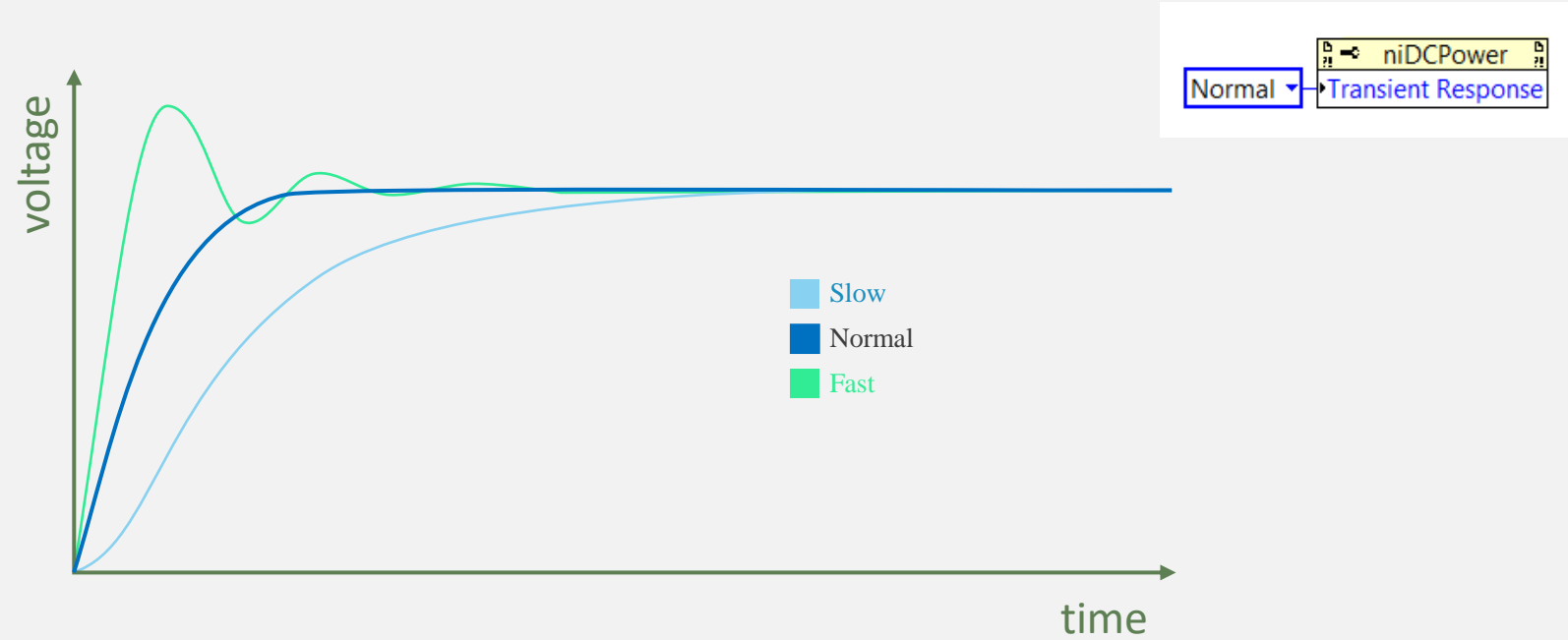
} “advanced” sequence
(>30 properties)

The 5 Tips

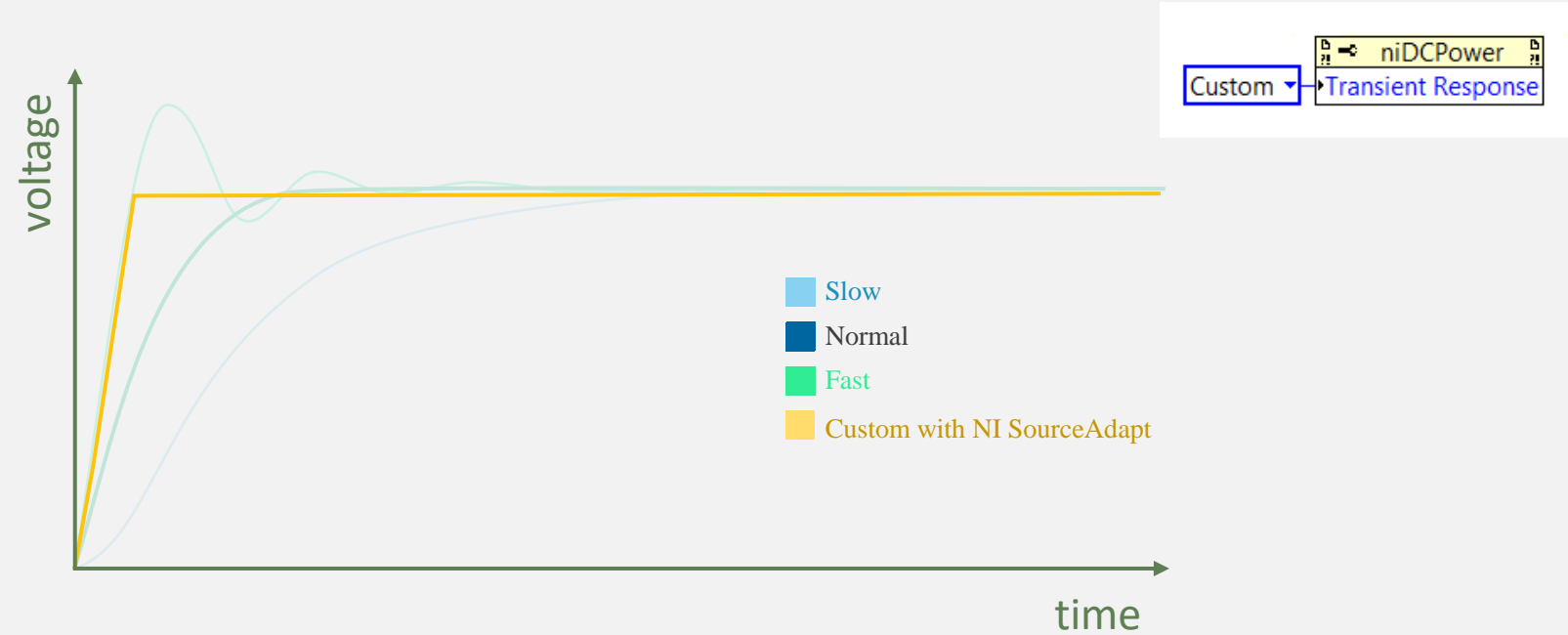


- 1 Choose the right equipment
- 2 Measure in parallel
- 3 Optimize source delay and aperture time
- 4 Utilize advanced instrument capabilities
- 5 **Tune transient response with Source Adapt**

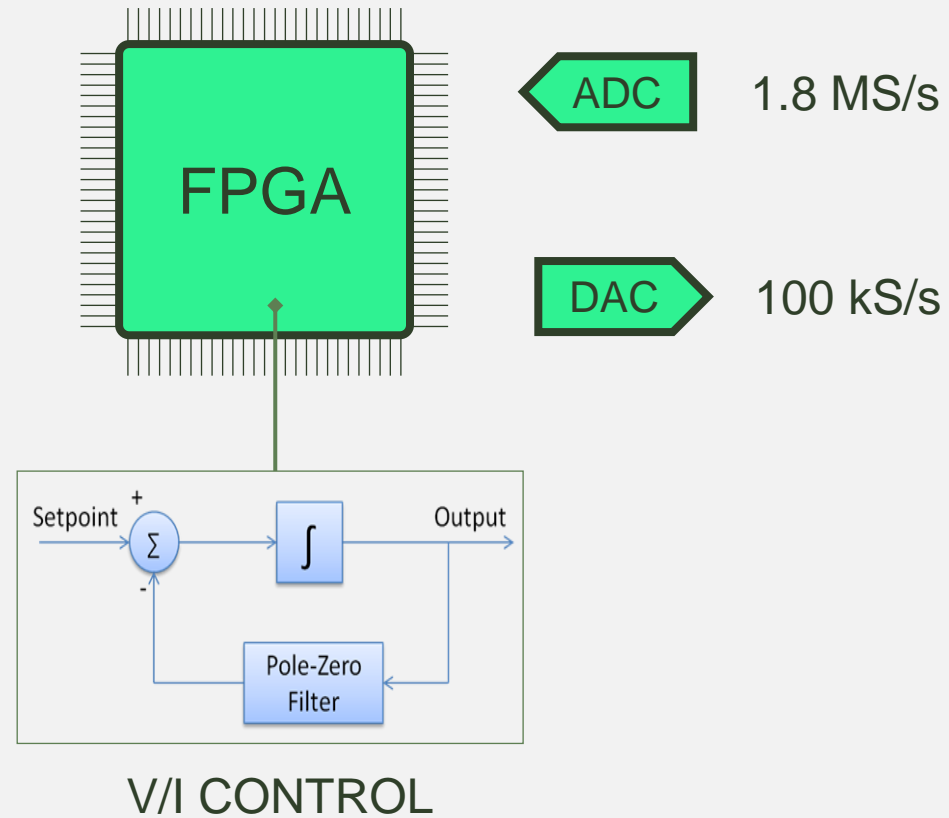
Transient Response and Rise Time



Transient Response and Rise Time



SourceAdapt: Digital Control Loop





SourceAdapt: Tuning in InstrumentStudio

The screenshot displays the NI InstrumentStudio interface for configuring and running a SourceAdapt sequence. A 'Channel Settings' dialog box is open, showing the following parameters:

- Channel 0: 100 uA
- Timing: Source delay (0.00000 s), Aperture time mode (Manual), Aperture time unit (Seconds), Aperture time (10.0000 μ s)
- SourceAdapt tuning parameters: Presets (Slow, Normal, Fast), Voltage (Gain bandwidth: 20.0000 kHz)
- Gain bandwidth: 200.000 kHz (with a logarithmic slider from 100 to 1 M 2 M)
- Compensation frequency: 10.0000 kHz
- Pole-zero ratio: 0.2500
- Hardware event output terminals: Source trigger, Source complete, Measure trigger, Measure complete (all set to None)

The main interface shows two waveforms. The top waveform is a square wave pulse with a duration of approximately 1.2 ms. The bottom waveform is a similar pulse with a duration of approximately 1.2 ms. The x-axis for both is labeled 'Time' and ranges from 480 μ s to 1.2 ms.

On the right side, the 'SMU/POWER SUPPLY PXIe-4141' control panel is visible, showing 'Horizontal & Acq.' settings (CAPTURE TIME: 1.2000 ms) and 'Channels' configuration (Channel 2: Voltage sequ...). Below this, a 'SEQUENCE BEGIN' section shows 'First setpo...' and 'Hold last...' buttons, and an 'OUTPUT' section with 'ON' button. A 'STEP COUNT' of 3 is displayed, along with a table of sequence steps:

Step	Voltage	Duration
1	0.0000 V	500 μ s
2	500.00 mV	500 μ s
3	0.0000 V	200 μ s

At the bottom, the current output values are displayed: 00.00154 V, 000.0186 μ A, and 28.62 pW.

The 5 Tips



- 1 **Choose the right equipment**
- 2 **Measure in parallel**
- 3 **Optimize source delay and aperture time**
- 4 **Utilize advanced instrument capabilities**
- 5 **Tune transient response with Source Adapt**



CONNECT

2023 AUSTIN

