Tektronix®
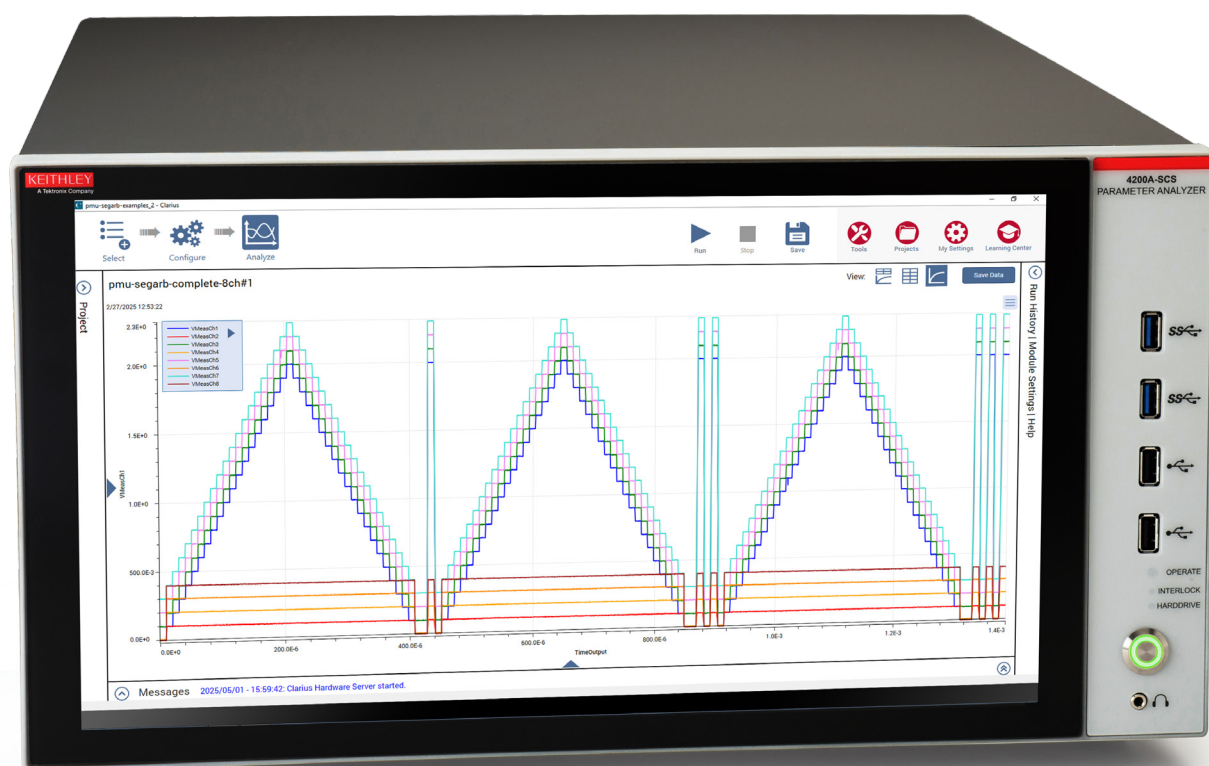
Utilizing Segment Arb™ Waveform for High Speed IV Measurements Using the 4225-PMU Ultra-Fast Pulse Measure Unit

APPLICATION NOTE

Introduction

High speed IV pulsing and measuring is often required for some semiconductor applications such as power device testing or to reduce the effects of self-heating caused by DC measurements. The two-channel 4225-PMU Ultra-Fast I-V Module (PMU) for the 4200A-SCS Parameter Analyzer supports many high speed source/measure applications. The PMU has three modes of ultra-fast IV source and measure modes: Pulsed IV, Waveform Capture and Segment ARB Waveform. These three modes are illustrated in **Figure 1**.

Pulsed IV
Pulse/Measure with DC-like results
Train, Sweep, Step modes

Waveform Capture
Time-based I and V measurements
Transient IV

Segment ARB Function
Multi-level pulsing
Arbitrary waveform generator

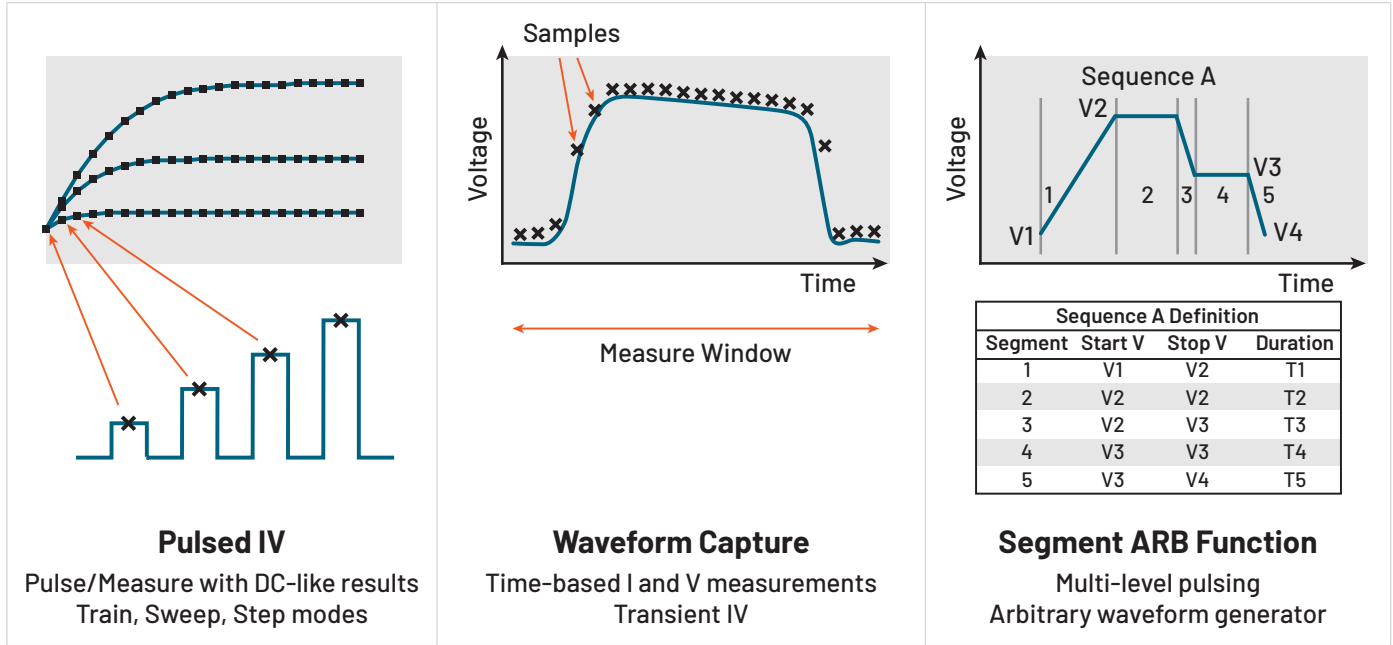| Sequence A Definition			
Segment	Start V	Stop V	Duration
1	V1	V2	T1
2	V2	V2	T2
3	V2	V3	T3
4	V3	V3	T4
5	V3	V4	T5

Figure 1. Ultra-Fast IV Modes of the 4225-PMU Pulse Measure Unit.

Pulsed IV is a pulsed source and a corresponding high speed, time-based measurement that provides DC-like results. For each pulse an average of readings is taken in a predefined window called "spot mean". Waveform capture mode outputs high-speed voltage pulses and measures the current and voltage response in the time domain. The Segment Arb function can be used to stress test a device using an AC signal during reliability cycling or in a multi-level waveform mode to program/erase memory devices. This type of pulsed sourcing involves outputting user-defined two-level or multi-level pulses using the built-in Segment Arb waveform function. Up to eight channels of Segment Arb waveforms are supported with the 4200A-SCS Clarius Software.

Starting with Clarius V1.14, the Clarius Test Library includes PMU Segment Arb waveform tests for up to eight channels of multi-level pulsing. In addition to the Segment Arb tests, the library includes tests for many PMU applications, including pulse IV and waveform capture measurements on a variety of devices including MOSFETs, diodes and memory devices. Starting with Clarius V1.13, PMU measurements can be remotely controlled using commands and an external computer.

This application note describes the Segment Arb waveform feature of the PMU and how to use the built-in Library tests for high speed, time-controlled pulsed applications.

Segment Arb Waveform

The Segment Arb waveform feature in the Clarius Software is a line segment waveform generator that can be used on either the 4225-PMU or the 4220-PGU Pulse Generator Unit (no measure). By entering values into a table, each channel of the PMU can be configured to output its own waveform composed of user-defined line segments, up to 2048. There are separate inputs for time interval, start and stop voltage values, start and stop measure window values, output trigger and output relay state (open or closed). Both spot mean and sample mode measurements are supported for each segment. Specific details of the Segment Arb™ waveform functionality are provided in the table in **Appendix A**.

An example PMU Segment Arb waveform is illustrated in **Figure 2**. This sequence has nine segments that generate a +35 V pulse for 1e-3 s and then a −35 V pulse for 1e−3 s. There are 10e−6 s segments for rise and fall times. (NOTE: The timing axis is not to scale.) Each of the nine segments has a unique start voltage, stop voltage and time as listed below:

Start Voltage (V): 0, 0, 35, 35, 0, 0, -35, -35, 0

Stop Voltage (V): 0, 35, 35, 0, 0, -35, -35, 0, 0

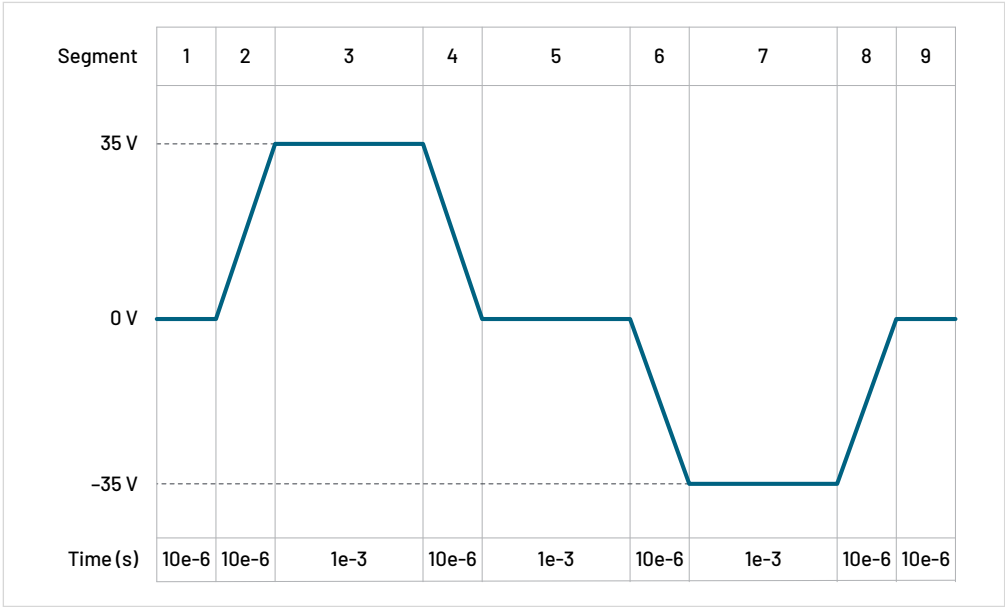**Segment Time (s):** 10e-6, 10e-6, 1e-3, 10e-6, 1e-3, 10e-6, 1e-3, 10e-6, 10e-6

Figure 2. Segment Arb Waveform Consisting of 9 Segments.

Using the Clarius Library Tests to Output Segment Arb Waveforms

The extensive 4200A-SCS built-in library includes tests and projects for easily configuring and outputting Segment Arb waveforms and sequences. The project tree of one of the library projects, *pmu-segarb-examples*, is shown in **Figure 3**. This project contains tests for outputting (and measuring I and V) of user-defined waveforms up to eight channels. Some of these tests enable sequencing of waveforms. Sequencing enables the segments to be repeated. Descriptions of these tests are in the following paragraphs.
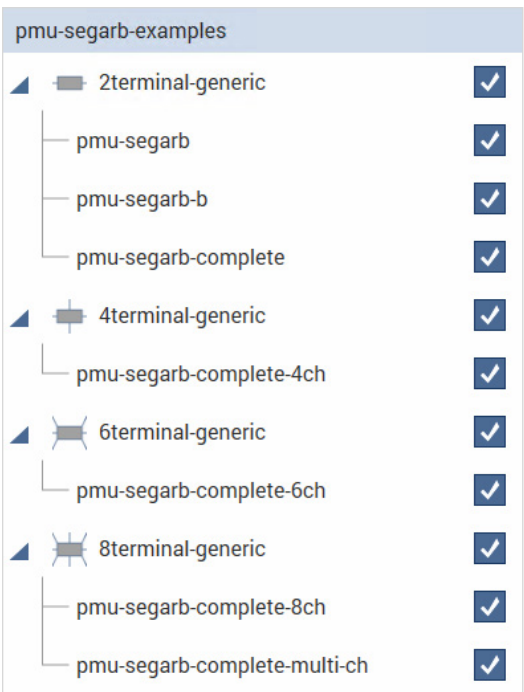

Figure 3. Project tree of the *pmu-segarb-examples* project.

The example library tests for Segment Arb offer the same basic control but vary by the number of channels, measurements mode (waveform, spot mean, or both) and sequencing capability. Input parameters that are common to all channels in each of the tests include:

- Number of segments
- Segment timing
- Trigger control
- Measurement type (waveform or spot mean)
- Measurement window (measure start and stop within a segment)

Input parameters that are defined separately for each channel:

- Voltage magnitude
- Voltage source range
- Current measure range
- Solid-state output relay control (both channels are either open or closed)

Descriptions for each of the tests are provided in the following paragraphs:

pmu-segarb: This test enables multi-segment waveform generation (Segment Arb) on two channels using a single PMU and measures and returns the waveform data (V and I vs. time, no spot mean). By default, this test is configured to output and measure an amplitude sweep using the Segment Arb pulse mode and measures the waveform (V and I, no spot mean).

pmu-segarb-b: This test is very similar to the *pmu-segarb* test except that the user can choose between waveform capture data or spot mean data to be returned.

pmu-segarb-complete: Configures multi-sequence, multi-segment waveforms (Segment Arb) on two channels using a single PMU and measures and returns either waveform (V and I vs. time) or spot mean data for each segment that has measurement enabled.

This test adds multiple sequences with up to 2048 segments. Each sequence can be looped to make a more complicated Segment Arb waveform.

pmu-segarb-complete-4ch: Same as the *pmu-segarb-complete* test except enables four channels using two PMUs and measures and returns either waveform (V and I vs. time) or spot mean data for each segment that has measurement enabled.

pmu-segarb-complete-6ch: Same as the *pmu-segarb-complete* test except enables six channels using three PMUs and measures and returns either waveform (V and I vs. time) or spot mean data for each segment that has measurement enabled.

pmu-segarb-complete-8ch: Same as the *pmu-segarb-complete* test except enables eight channels using four PMUs and measures and returns either waveform (V and I vs. time) or spot mean data for each segment that has measurement enabled.

pmu-segarb-complete-multi-ch: This test is like the other *pmu-segarb-complete* tests except it adds the ability to run any number of channels from one to eight. The ability to select the desired number of channels is achieved through channel control checkboxes for each channel. To use a specific channel in a test, select the corresponding checkbox for that channel.

Using the Segment Arb Library Test Examples

This section describes how to use the Segment Arb library tests including the Segment Arb configuration table and resulting outputs. Three tests are used as examples: *pmu-segarb*, *pmu-segarb-complete-4ch*, and *pmu-segarb-complete-multi-ch*.

pmu-segarb test

The two-channel *pmu-segarb* test has basic Segment Arb functionality including the ability to configure multi-segment waveforms, measure both I and V of the waveforms and return the data to the Sheet and Graph in the Analyze view. The test is setup in the Configure view, which is shown in **Figure 4**.
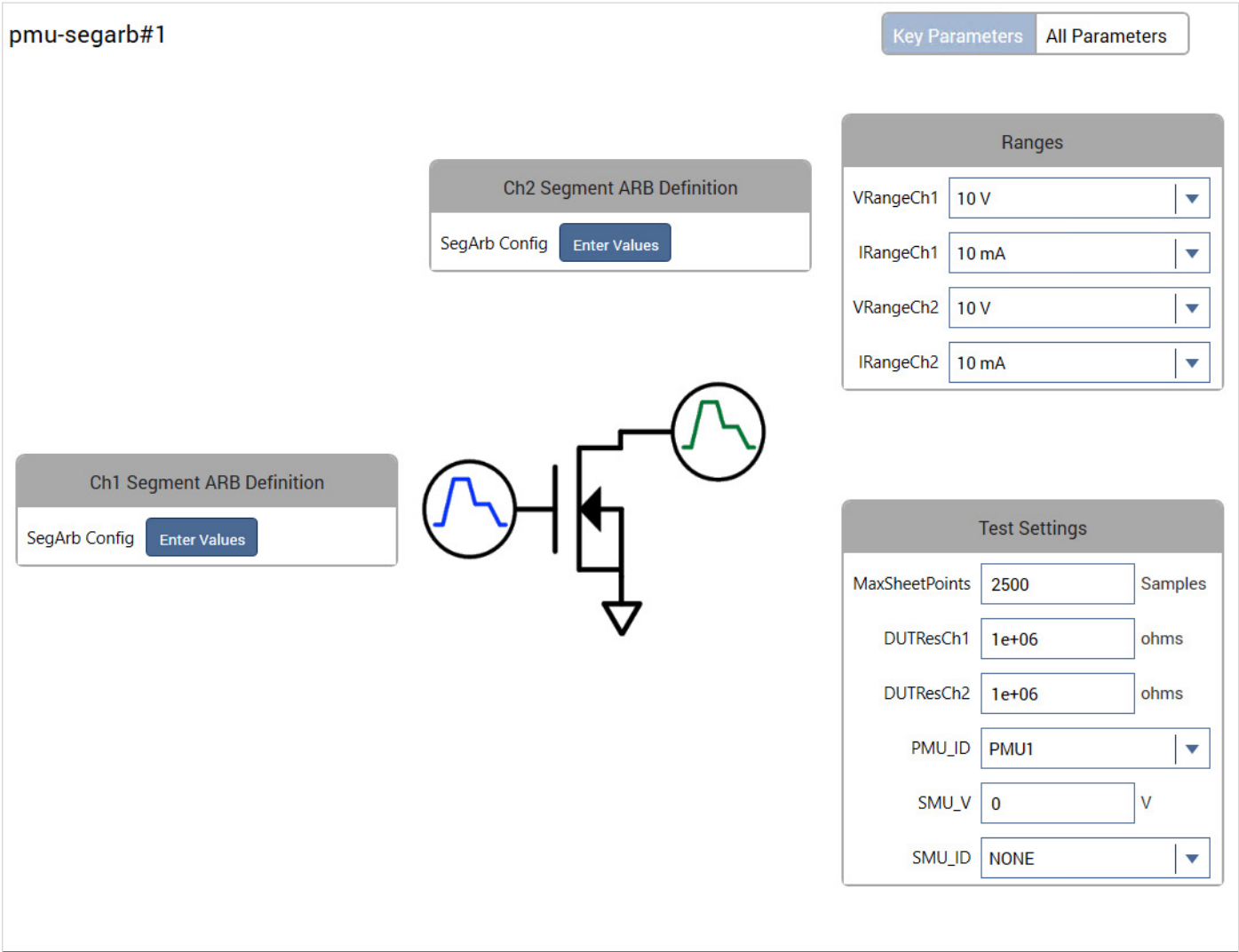

Figure 4. *pmu-segarb* test Configure view.

The Segment Arb configuration tables are accessed from **Ch1** or **Ch2 Segment ARB Definition**. By selecting **Enter Values**, the **Segment Arb Configuration** table for Ch2 opens as shown in **Figure 5**. From this table the start voltage (StartVCh2), stop voltage (StopVCh2), segment time (SegTime), solid state relay state (SSRCtrlCh2) and trigger output (SegTrigOut) are configured for Ch2. SegTrigOut turns the TTL-level trigger output pulse on or off (1/0). The pulse is used to synchronize the pulse output with the operations of an external instrument.

The bottom of the configuration menu shows a preview window of the defined voltage vs. time waveform.
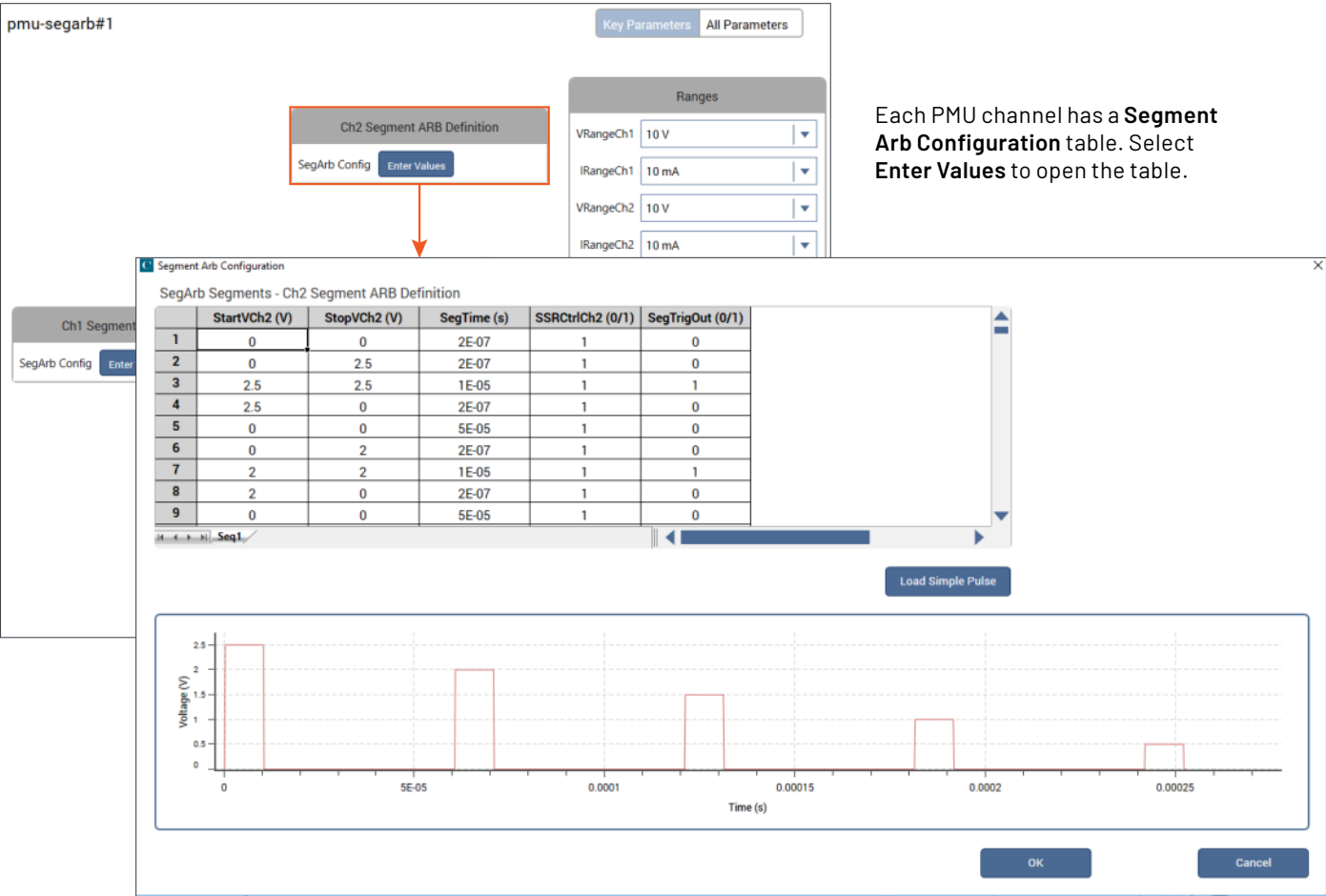

Each PMU channel has a **Segment Arb Configuration** table. Select **Enter Values** to open the table.

Figure 5. Segment Arb Configuration table for Ch2 of *pmu-segarb* test.

After entering the values for each column, select **OK** to save the configuration. Selecting **Run** will execute the test with the defined configuration. If any errors occur, a message will be shown in the Messages window at the bottom of the screen. The full list of error codes and descriptions for the Segment Arb tests can be found in **Appendix B**.

Once the test is executed, the current and voltage (waveform mode only) from each channel and the time output are returned to the Sheet in the Analyze view. The voltage vs. time graphs of both Ch1 and Ch2 from executing the *pmu-segarb* test are shown in **Figure 6**.
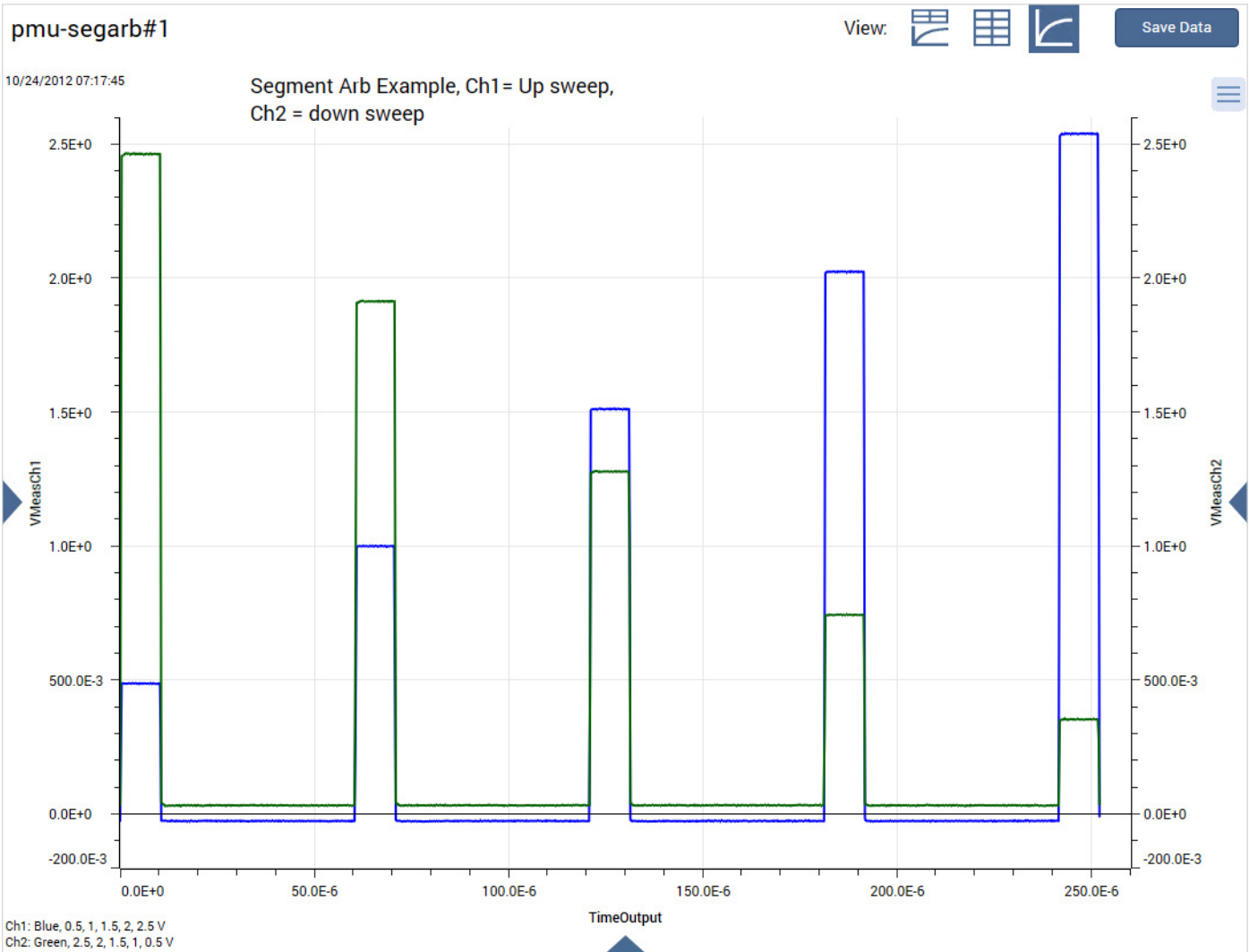

Figure 6. Voltage vs. Time graphs of Ch1 and Ch2 in the Analyze view of the *pmu-segarb* test.

pmu-segarb-complete-4ch test

The *pmu-segarb-complete-4ch* test is a four-channel test that requires two PMUs. All the **pmu-segarb-complete** tests add more measurement controls and sequencing capability compared to the *pmu-segarb* and *pmu-segarb-b* tests. The expanded Segment Arb Configuration menu is shown in **Figure 7**.

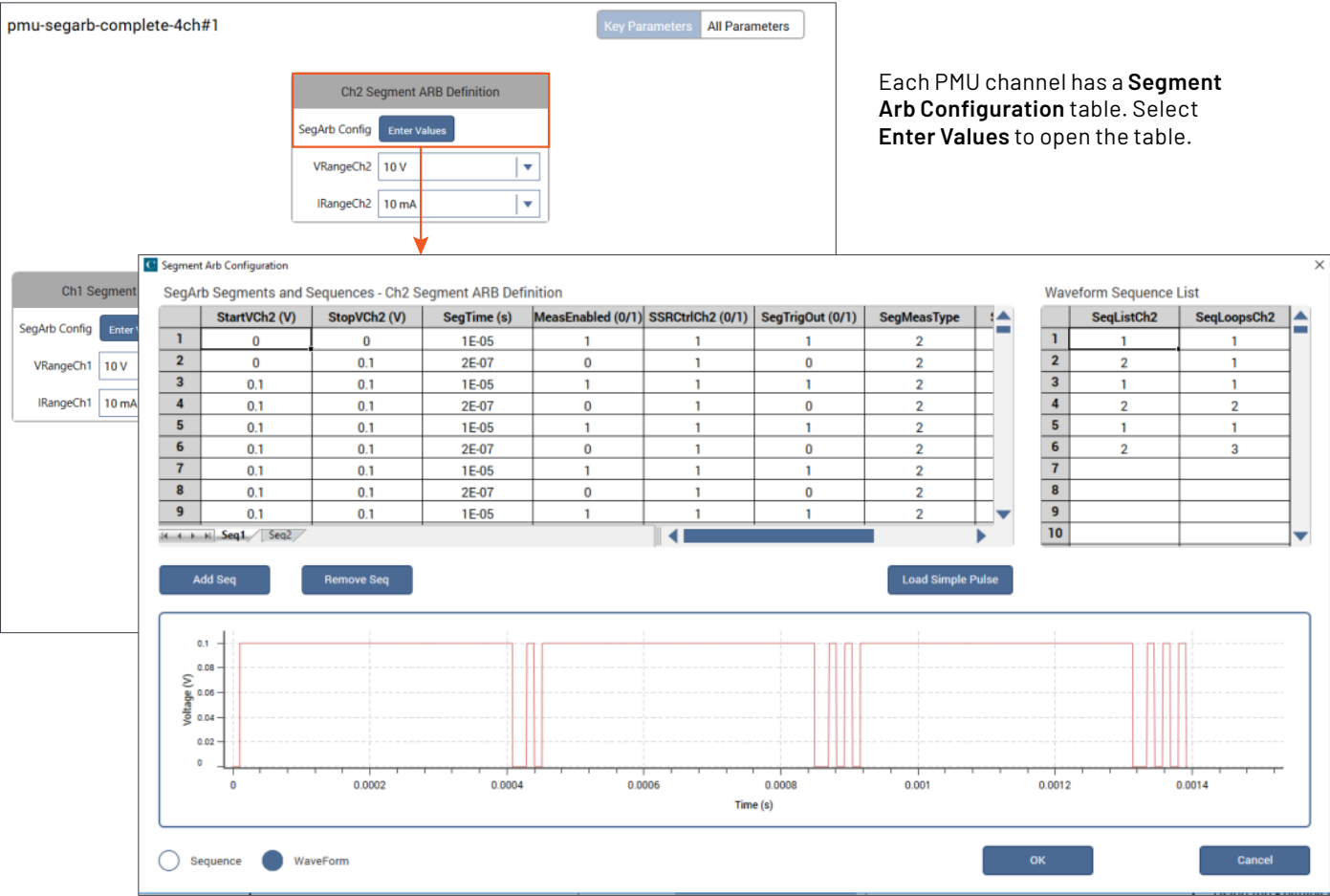Each PMU channel has a **Segment Arb Configuration** table. Select **Enter Values** to open the table.

Figure 7. Segment Arb Configuration Menu for *pmu-segarb-complete-4ch* test.

Each channel has its own Segment Arb Configuration menu with three distinct sections. These are further explained in the following paragraphs:

1. **SegArb Segments and Sequences**: This section enables the entry of each configurable SegARB variable. These variables, in order, are start voltage, stop voltage, segment time, enabling the measurement, control of the high endurance output relay, trigger values, measurement types, measurement start (as a percentage of the pulse) and measurement stop (as a percentage of the pulse). The tabs at the bottom of the menu are used to switch between the different sequences. Underneath this are buttons for adding a sequence, removing a sequence and loading a simple pulse.

2. **Waveform Sequence List:** The top right-hand section shows the sequence list of the waveform, indicating the order in which selected sequences will be output. The left-most column is the order of the sequences, and the right-most column shows how many times it loops through the sequence before moving on to the next one. The entire waveform can be viewed in the preview window when the waveform preview option is selected.

3. **Preview Window:** The bottom of the configuration menu shows a preview window. This preview window shows a voltage vs. time graph of the defined waveform. The user can toggle between viewing the selected sequence or viewing the entire waveform.

When executed, this test returns to the Sheet in the Analyze view the measured current and voltage from each of the four channels as well as the time output. **Figure 8** shows the measured voltage from all four channels graphed.
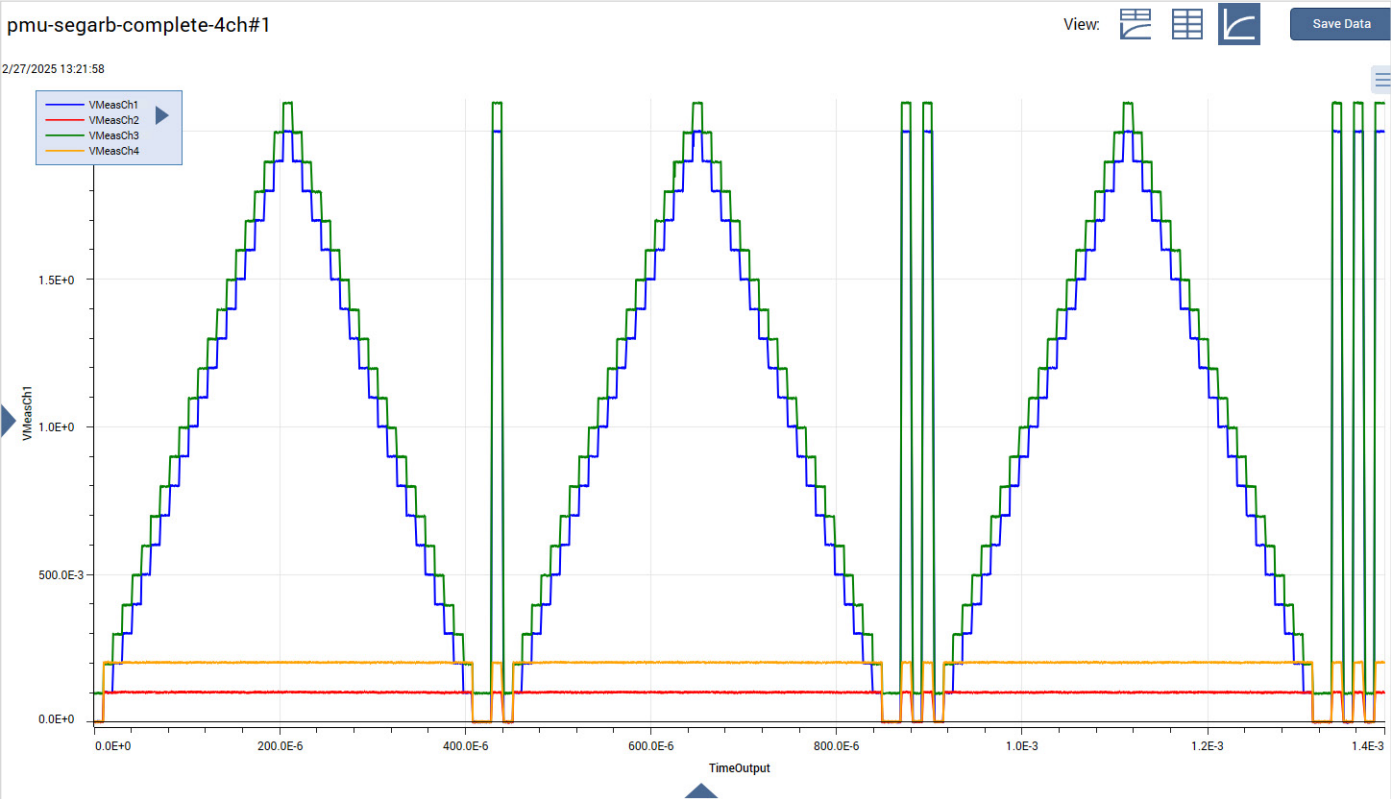

Figure 8. *pmu–segarb–complete–4ch* test results graphed in the Analyze view.

If the output of the four PMU channels is connected to the input of four channels of the Tektronix 5 Series MSO Oscilloscope, the results of executing the test appear in the scope capture in **Figure 9**.
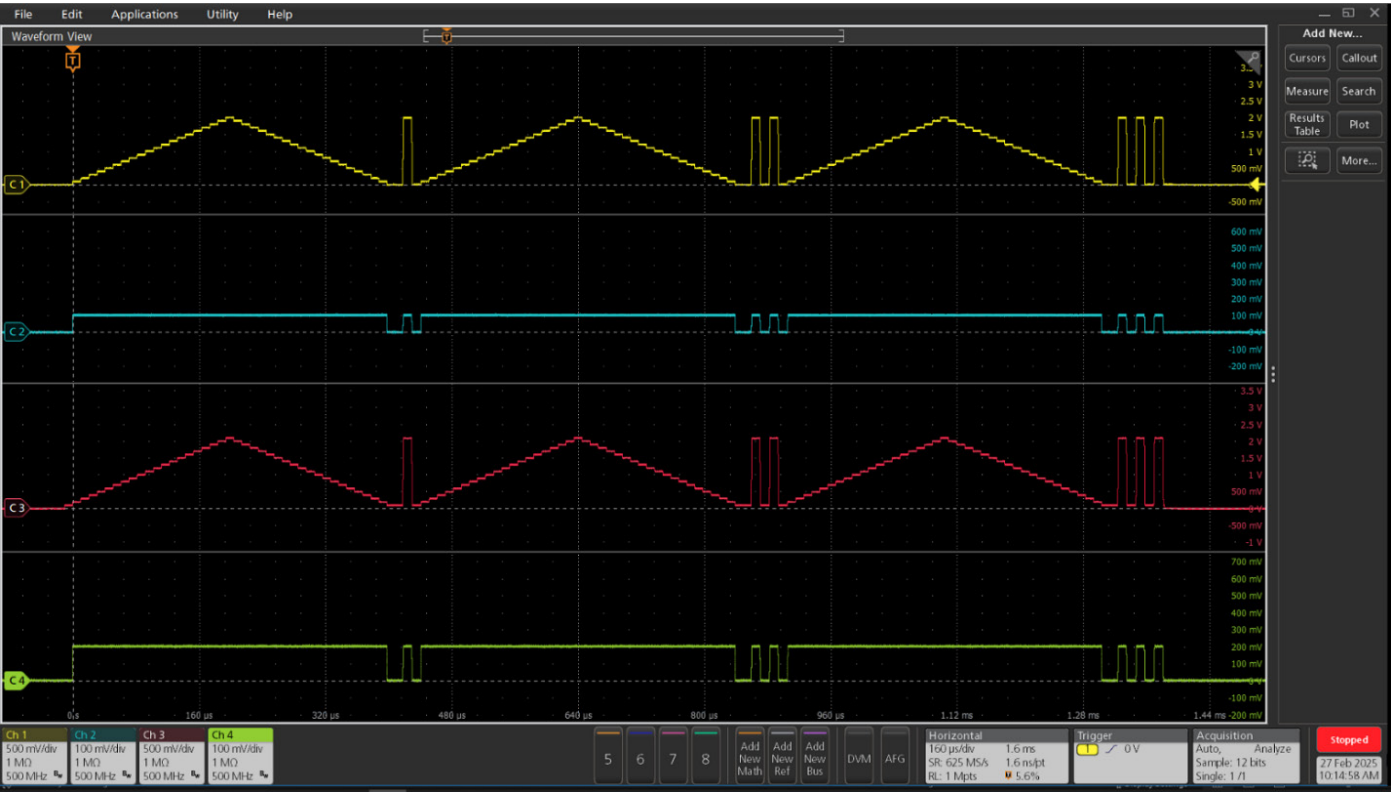

Figure 9. Output of the *pmu-segarb-complete-4ch* test on a Tektronix 5 Series MSO Oscilloscope.

pmu-segarb-complete-multi-ch test

This test is similar to the *pmu-segarb-complete-4ch* test but adds additional flexibility. This module allows running any number of channels from 1 through 8 using a set of channel control checkboxes for channels 1 through 8. To use a channel during the test, check the corresponding box for that channel. The Configure view of this test with the additional checkboxes are shown in **Figure 10**.

Figure 10. *pmu-segarb-complete-multi-ch* test with individual Channel Control check boxes.

As shown in **Figure 10**, the user can select any number of channels, including an odd number of channels. With these additional capabilities, there are 255 different channel combinations that can be configured. The voltage vs. time outputs of the five channels enabled in this test are shown in **Figure 11**.
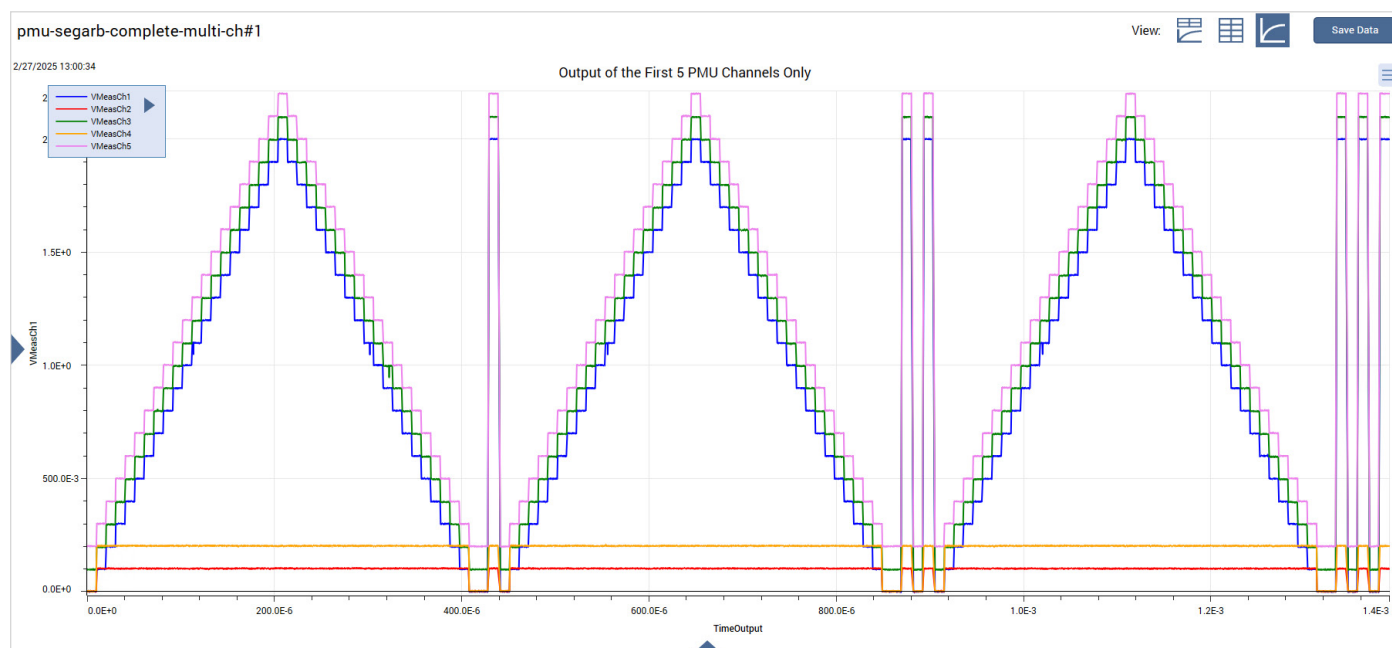

Figure 11. Voltage vs. Time output graphs in the Analyze view of the five channels configured in the *pmu-segarb-complete-multi-ch* test.

Remote Control of the PMU Segment Arb Functionality

Besides using the interact Clarius Software to control the PMU Segment Arb functionality, the 4200A-SCS Parameter Analyzer with the 4225-PMU can be remotely controlled by an external computer for test automation. The Keithley External Control Interface (KXCI) enables remote control of the instrument modules in the 4200A-SCS by sending commands from a computer. The controlling computer can be connected to the 4200A-SCS through GPIB or ethernet to remotely send the KXCI commands using a coding environment. A separate application note, "Pulse IV Test Automation with the Keithley 4225-PMU Pulse Measure Unit", describes how to use the PMU remotely and includes example code.

Conclusion

In conclusion, the combination of the Clarius Software and the pulsing capabilities of the 4225-PMU Ultra-Fast I-V Module for the 4200A-SCS Parameter Analyzer enables up to eight channels (four PMUs) of Segment Arb outputs. The Segment Arb capability can be configured through the Clarius Software or through remote control using KXCI. Segment Arb is a powerful tool for semiconductor testing, providing high-speed, time-controlled pulsing for a wide range of applications.

Appendix A: Segment Arb Library Test Details

Category	Details
Time per Segment	**With/without measurement:** 20 ns up to 1 s (10 V range), 50 ns up to 1 s (40 V range)
Voltage Magnitude	**Start Voltage:** –40 V to +40 V or –10 V to +10 V (40 & 10 V range, respectively) **Stop Voltage:** –40 V to +40 V or –10 V to +10 V (40 & 10 V range, respectively)
Number of Segments	**Per sequence:** 3 to 2048 segments
Number of Sequences	Up to 512 sequences
Maximum Number of Channels	Eight channels (four PMUs) using the *pmu-segarb-complete-8ch* test or the *pmu-segarb-complete-multi-ch* test
Measurement Types	No measurements, spot mean discrete, waveform discrete, spot mean average, waveform average
Sequence Loop (SeqLoop)	Up to 2.14e9 times
Additional Rules	The time duration of one segment (ex. Segment 1) must be the same across all active channels. All input arrays in a sequence must be the same size. Voltages of all segment transitions must be seamless. The end of one segment must match the beginning of the next segment.

Appendix B: Segment Arb Test Error Codes

The following table lists the error codes that may occur when executing one of the Segment Arb tests. The error codes appear in the second row and second column of the Sheet in the Analyze view.

Error Codes	Description
0	OK.
–3	Segment sequence time duration MUST be same for channels.
–4	Corrupt SegArb Sequence definition.
–122	Illegal value for parameter. example: pulse_ranges(): Illegal value for parameter #7. Ensure that current measure range is appropriate for the chosen voltage range.
–233	Cannot force when not connected. Ensure that specified SMU is not connected through or associated with an RPM. If all SMUs are associated with RPM modules, choose NONE to permit the test to run.
–804	Usually caused by PMU V source and I measure range setting conflict.
–820	seg_arb_sequence(): PMU segment start value xxV at index 1 does not match previous segment stop value of yyV. Problem with Segment ARB voltage definition. Review start or stop voltages. Check to see if StartV matches previous StopV. Check to see if any voltages > Vrange.
–835	seg_arb_sequence(): Using the specified sample rate of xxxxx samples/s, the time (yyyy) for sequence 1 is too short for a measurement. This means that there is a segment with a time duration too short to permit any samples to be made with the chosen sample rate of xxxxx samples/s. There must be at least 1 sample per measured segment. Increase the permitted number of samples by increasing the value for MaxSheetPoints, or increase the time duration of all segments with time yyyy.
–846	seg_arb_sequence(): Maximum Source Voltage Reached: Requested voltage across DUT resistance exceeds maximum voltage available. Ensure that all voltages are < PMU Voltage Range (VRangeCh1 and VRangeCh2). When the DUT Resistance is set to a lower value (< 1 kΩ), also check that the voltage is still possible by calculating Imax and Vmax. Imax = V source range/(50 Ω + DUT Resistance) Vmax = Imax * DUT Resistance. If Vmax is < SegARB voltage requested Error –846 will occur. Reduce the requested voltage to allow test to run.
–17001	Wrong card Id. Check PMU and SMU names.
–17002	Failure to assign card ID handle. Check PMU and/or SMU names.
–17003	Duplicate PMU IDs were used during the test. Ensure that each PMU ID is unique.

Contact Information:

Australia 1 800 709 465

Austria* 00800 2255 4835

Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777

Belgium* 00800 2255 4835

Brazil +55 (11) 3530-8901

Canada 1 800 833 9200

Central East Europe / Baltics +41 52 675 3777

Central Europe / Greece +41 52 675 3777

Denmark +45 80 88 1401

Finland +41 52 675 3777

France* 00800 2255 4835

Germany* 00800 2255 4835

Hong Kong 400 820 5835

India 000 800 650 1835

Indonesia 007 803 601 5249

Italy 00800 2255 4835

Japan 81 (3) 6714 3086

Luxembourg +41 52 675 3777

Malaysia 1 800 22 55835

Mexico, Central/South America and Caribbean 52 (55) 88 69 35 25

Middle East, Asia, and North Africa +41 52 675 3777

The Netherlands* 00800 2255 4835

New Zealand 0800 800 238

Norway 800 16098

People's Republic of China 400 820 5835

Philippines 1 800 1601 0077

Poland +41 52 675 3777

Portugal 80 08 12370

Republic of Korea +82 2 565 1455

Russia / CIS +7 (495) 6647564

Singapore 800 6011 473

South Africa +41 52 675 3777

Spain* 00800 2255 4835

Sweden* 00800 2255 4835

Switzerland* 00800 2255 4835

Taiwan 886 (2) 2656 6688

Thailand 1 800 011 931

United Kingdom / Ireland* 00800 2255 4835

USA 1 800 833 9200

Vietnam 12060128

* European toll-free number. If not accessible, call: +41 52 675 3777

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