Keithley Sequence Tools Library

Introduction

The Series 2600B System SourceMeter® and Series 2650A High Power SourceMeter SMU Instruments provide direct support for sweeping a voltage or current source through a list of values using the list sweep commands. One limitation of these commands is that the source function cannot change during the sweep. For applications that require an arbitrary mix of voltage and current steps, Keithley provides a user-installable `CreateSequence` command.

Installation

To install the Sequence Tools Library:

1. Save `InstallSeqTools.tsp` to a USB flash drive.
2. Insert the USB flash drive into the instrument.
3. On the instrument, select **MENU > SCRIPT > LOAD > USB1 > InstallSeqTools.tsp** to load the script onto the instrument.
4. After the script is loaded, select **SAVE-INTERNAL**, then select **YES**.
5. Exit out of all menus.

Basic usage

The `CreateSequence` command takes an array of sequence steps as its single parameter:

SequenceVar = CreateSequence(*steps*)

Where *SequenceVar* is the sequence that is created.

Each step is an array with the elements shown in the following table.

[1] Source Function	Either smu*X*.OUTPUT_DCVOLTS or smu*X*.OUTPUT_DCAMPS
[2] Source Level	Any valid source level for the selected source function.
[3] Source Range	Any valid range for the selected source function and level. If the source range is set to the same value as the source level, an appropriate range is selected automatically.
[4] Limit	For a voltage source, sets the current limit. For a current source, sets the voltage limit. The combination of limit and source level must not exceed the power envelope of the instrument (safe operating area).
[5] Measure Aperture	The duration of the measurement in number of power line cycles (NPLC). If the value is set to nil, no measurement is made during this step.
[6] Settle Time	The amount of time that the source should be allowed to settle before a measurement is made. The minimum achievable delay is approximately 1 ms.

To access the information in the sequence, you use the attributes described in the following table.

Attribute	Description
SequenceVar.results	The results of any measurements made during the sequence are stored in this table. To clear the results for this sequence, assign an empty table to the results field: *SequenceVar*.results = {}
SequenceVar.run()	Once a sequence has been created, calling the run function causes the complete sequence to execute.
SequenceVar.smu	Allows assignment of a SMU channel to the sequence. The default is smua.

NOTE

Only measurements are stored in the results table. Other data, such as source values and timestamps, are not available.

Basic example

Assume the following sequence is required:

1. Source 10 mA on the 100 mA range with a 5 V limit, wait 100 ms, measure voltage at 1 PLC.
2. Source 2 V on the 2 V range with a 20 mA limit, wait 50 ms, measure current at 0.1 PLC.

This invocation of `CreateSequence` captures the requirement:

```
local sequence = CreateSequence({
    {smua.OUTPUT_DCAMPS, 0.01, 0.1, 5, 1.0, 0.1},
    {smua.OUTPUT_DCVOLTS, 2.00, 2.0, 0.02, 0.1, 0.05}
})
```

To run the sequence and print the requested measurements:

```
sequence.run()
printbuffer(1, 2, sequence.results)
```

Example output is:

```
2.07620e+00, 6.47210e-03
```

Note that the output turns on automatically if it is not already on. After the sequence is complete, you can turn off the output by setting the smu*X*.`source.output` command to smu*X*.`OUTPUT_OFF`. For channel A, send:

```
smua.source.output = smua.OUTPUT_OFF
```

For channel B, send:

```
smub.source.output = smub.OUTPUT_OFF
```

Advanced usage

You can use the following attributes to refine use of the `CreateSequence` command.

SequenceVar.autozero_once()

For sequences that have multiple measurement apertures, you may encounter a delay as the instrument switches from one aperture to the next. To prevent this delay from occurring during the sequence run, you can cache up to eight aperture values. The `autozero_once` command determines which unique apertures are present in the sequence and then caches the values for later use.

Note that if `autozero_once` is used, it should be called periodically to prevent measurement drift. See smu*X*.`measure.autozero`, described in the instrument reference manual, for more information.

Usage

SequenceVar.`autozero_once()`

Where *SequenceVar* is the sequence object that was created.

SequenceVar.run_index()

This attribute runs a single step from the sequence. The measurement result is returned directly instead of being appended to the results table.

Usage

```
result = SequenceVar.run_index(index)
```

Where:

- *result* is the measurement
- *SequenceVar* is the sequence object that was created
- *index* is the number of the step that you want to run

SequenceVar.run_subsequence()

This attribute runs all sequence steps from *start_index* to *stop_index* and appends any measurement results to the results table.

To clear all previous results from the results table, send *SequenceVar*.results = {}.

Usage

```
SequenceVar.run_subsequence(start_index, stop_index)
```

Where:

- *SequenceVar* is the sequence object that was created
- *start_index* is the number of the first index to run
- *stop_index* is the number of the last index to run

SequenceVar.run_subset()

This attribute runs the sequence steps specified in *index_table* and appends any measurement results to the results table. The indices can be in any order and duplication of indices is allowed.

To clear all previous results from the results table, send *SequenceVar*.results = {}.

For example:

```
sequence.run_subset({1,5,1,1,3})
```
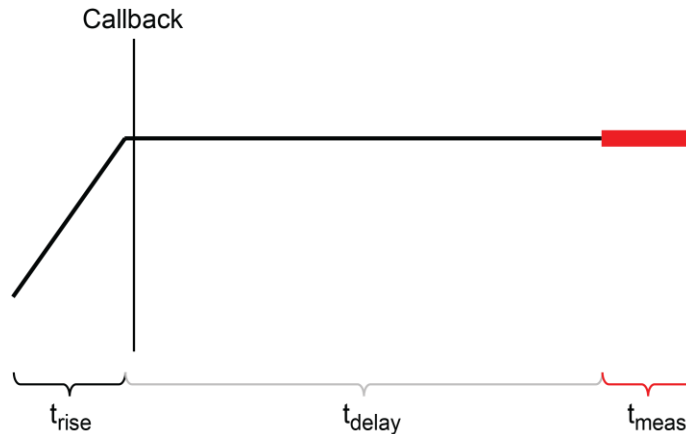
Usage

```
SequenceVar.run_subset(index_table)
```

Where:

- *SequenceVar* is the sequence object that was created
- *index_table* specifies the sequence steps to run

Running arbitrary TSP code during settle time

Each sequence step has one additional index beyond the basic six that is reserved for specifying a callback function and its arguments. The callback is executed during the step's settle time. See the following diagram for an illustration of the timing.

Note that the callback only affects the overall sequence timing if its execution time cannot be absorbed by the settle time for the step.

The function signature for the callback is `function(`*`sequence`*`, …)`, where the sequence parameter takes a reference to the presently running sequence. This allows examination or modification of the *`sequence.results`* table during the execution of the callback.

Advanced example

This example creates the same sequence as the Basic Example, but waits for the user to press the TRIG key before making the first measurement. Note that the sequence parameter is ignored in this example. The output is turned off before printing the results.

```
local function wait(seq, timeout)
    display.trigger.wait(timeout)
end

local sequence = CreateSequence({
    {smua.OUTPUT_DCAMPS, 0.01, 0.1, 5, 1.0, 0.1, {wait, 100}},
    {smua.OUTPUT_DCVOLTS, 2.00, 2.0, 0.02, 0.1, 0.05}
})

sequence.run()
smua.source.output = smua.OUTPUT_OFF
printbuffer(1, 2, sequence.results)
```

Example output is:

```
2.07774e+00, 6.40932e-03
```

The following safety precautions should be observed before using this product and any associated instrumentation. Although some instruments and accessories would normally be used with nonhazardous voltages, there are situations where hazardous conditions may be present.

This product is intended for use by personnel who recognize shock hazards and are familiar with the safety precautions required to avoid possible injury. Read and follow all installation, operation, and maintenance information carefully before using the product. Refer to the user documentation for complete product specifications.

If the product is used in a manner not specified, the protection provided by the product warranty may be impaired.

The types of product users are:

Responsible body is the individual or group responsible for the use and maintenance of equipment, for ensuring that the equipment is operated within its specifications and operating limits, and for ensuring that operators are adequately trained.

Operators use the product for its intended function. They must be trained in electrical safety procedures and proper use of the instrument. They must be protected from electric shock and contact with hazardous live circuits.

Maintenance personnel perform routine procedures on the product to keep it operating properly, for example, setting the line voltage or replacing consumable materials. Maintenance procedures are described in the user documentation. The procedures explicitly state if the operator may perform them. Otherwise, they should be performed only by service personnel.

Service personnel are trained to work on live circuits, perform safe installations, and repair products. Only properly trained service personnel may perform installation and service procedures.

Keithley products are designed for use with electrical signals that are measurement, control, and data I/O connections, with low transient overvoltages, and must not be directly connected to mains voltage or to voltage sources with high transient overvoltages. Measurement Category II (as referenced in IEC 60664) connections require protection for high transient overvoltages often associated with local AC mains connections. Certain Keithley measuring instruments may be connected to mains. These instruments will be marked as category II or higher.

Unless explicitly allowed in the specifications, operating manual, and instrument labels, do not connect any instrument to mains.

Exercise extreme caution when a shock hazard is present. Lethal voltage may be present on cable connector jacks or test fixtures. The American National Standards Institute (ANSI) states that a shock hazard exists when voltage levels greater than 30 V RMS, 42.4 V peak, or 60 VDC are present. A good safety practice is to expect that hazardous voltage is present in any unknown circuit before measuring.

Operators of this product must be protected from electric shock at all times. The responsible body must ensure that operators are prevented access and/or insulated from every connection point. In some cases, connections must be exposed to potential human contact. Product operators in these circumstances must be trained to protect themselves from the risk of electric shock. If the circuit is capable of operating at or above 1000 V, no conductive part of the circuit may be exposed.

For maximum safety, do not touch the product, test cables, or any other instruments while power is applied to the circuit under test. ALWAYS remove power from the entire test system and discharge any capacitors before: connecting or disconnecting cables or jumpers, installing or removing switching cards, or making internal changes, such as installing or removing jumpers.

Do not touch any object that could provide a current path to the common side of the circuit under test or power line (earth) ground. Always make measurements with dry hands while standing on a dry, insulated surface capable of withstanding the voltage being measured.

For safety, instruments and accessories must be used in accordance with the operating instructions. If the instruments or accessories are used in a manner not specified in the operating instructions, the protection provided by the equipment may be impaired.

Do not exceed the maximum signal levels of the instruments and accessories. Maximum signal levels are defined in the specifications and operating information and shown on the instrument panels, test fixture panels, and switching cards.

Chassis connections must only be used as shield connections for measuring circuits, NOT as protective earth (safety ground) connections.

The **WARNING** heading in the user documentation explains hazards that might result in personal injury or death. Always read the associated information very carefully before performing the indicated procedure.

The **CAUTION** heading in the user documentation explains hazards that could damage the instrument. Such damage may invalidate the warranty.

The **CAUTION** heading with the ⚠ symbol in the user documentation explains hazards that could result in moderate or minor injury or damage the instrument. Always read the associated information very carefully before performing the indicated procedure. Damage to the instrument may invalidate the warranty.

Instrumentation and accessories shall not be connected to humans.

Before performing any maintenance, disconnect the line cord and all test cables.

To maintain protection from electric shock and fire, replacement components in mains circuits — including the power transformer, test leads, and input jacks — must be purchased from Keithley. Standard fuses with applicable national safety approvals may be used if the rating and type are the same. The detachable mains power cord provided with the instrument may only be replaced with a similarly rated power cord. Other components that are not safety-related may be purchased from other suppliers as long as they are equivalent to the original component (note that selected parts should be purchased only through Keithley to maintain accuracy and functionality of the product). If you are unsure about the applicability of a replacement component, call a Keithley office for information.

Unless otherwise noted in product-specific literature, Keithley instruments are designed to operate indoors only, in the following environment: Altitude at or below 2,000 m (6,562 ft); temperature 0 °C to 50 °C (32 °F to 122 °F); and pollution degree 1 or 2.

To clean an instrument, use a cloth dampened with deionized water or mild, water-based cleaner. Clean the exterior of the instrument only. Do not apply cleaner directly to the instrument or allow liquids to enter or spill on the instrument. Products that consist of a circuit board with no case or chassis (e.g., a data acquisition board for installation into a computer) should never require cleaning if handled according to instructions. If the board becomes contaminated and operation is affected, the board should be returned to the factory for proper cleaning/servicing.

Safety precaution revision as of June 2017.