Unified measurement software

UMS

Reference manual

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Table of Content

List of devices supported by UMS:

The unified measurement software currently supports the devices listed below. Please keep in mind that the functionality was adapted to our needs so there might be functionalities which are not yet implemented in a specific device.

Keithley measurement devices:

- Keithley 740
- Keithley 2000
- Keithley 2001
- Keithley 2182A
- Keithley 2601B
- Keithley 2602B
- Keithley 2612B
- Keithley 2700
- Keithley 2701
- Keithley 6517B
- Keithley 7001
- Keithley 6220
- Keithley 4200 SCS

Tektronix devices:

- Tektronix AFG2021
- Tektronix AFG3021C

Power supplies:

- TTI QL564TP

Impedance bridges:

- Gamry Reference 600
- Zahner IM6
- Solartron 1260

Oven controllers:

- Eurotherm 2404
- Eurotherm 2416
- Eurotherm 3216
- Eurotherm 3500
- Eurotherm nanodac

GPIB Adapters:

- Prologix GPIB-USB Adapter
- Prologix GPIB-Ethernet Adapter

Function reference:

General remarks:

- If not stated otherwise, all function arguments are in SI units.
- Arguments, which already have a default value, do not need to be specified if you want to keep them at the default value.
- Before passing the *device* to a function, make sure you initailized it.
- `Code examples are set in this particular font`

Preforming of memristors

```
preforming_ramp(device,start_voltage,ramp_speed_1,top_voltage,hold_time,ramp_spe
ed_2,end_voltage,compliance_current=0,new_row=False, GUI=True)
```

Return value are the following arrays: `[data_V_I,data_V_t,data_I_t]`

This function is used to preform memristors before they are cycled.

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date only keithley_2601B, keithley_2602B and keithley_2612B and keithley_6517B can be used. Keep in mind that keithley_6517B has no compliance current capability.
start_voltage	V	Where you want to start
ramp_speed_1	V/s	
top_voltage	V	
hold_time	s	You can also set this to 0. Then it does not wait
ramp_speed_2	V/s	Needs to be negative
end_voltage	V	You can also set this voltage equal to *bottom_voltage*. Then you only cycle in the positive branch
compliance_current	A	CC (Default=0 means no CC is applied)
new_row	Default: False	Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI	Default: True	Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
preforming_ramp_with_current_limit(device,start_voltage,ramp_speed_1,top_voltage
,hold_time,ramp_speed_2,end_voltage,stop_current,new_row=False, GUI=True)
```

Return value are the following arrays: `[data_V_I,data_V_t,data_I_t]`

This function does basically the same as the above one, but was especially designed for the High resistance meter Keithley 6517B which does not support compliance currents. Therefore we replaced it by a certain „stop_current“.

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date only keithley_2601B, keithley_2602B and keithley_2612B and keithley_6517B can be used. Keep in mind that keithley_6517B has no compliance current capability.
start_voltage	V	Where you want to start
ramp_speed_1	V/s	
top_voltage	V	
hold_time	s	You can also set this to 0. Then it does not wait
ramp_speed_2	V/s	Needs to be negative
end_voltage	V	You can also set this voltage equal to *bottom_voltage*. Then you only cycle in the positive branch
stop_current	A	If this specific current value is reached, the function immediately stops and no further voltage is applied.
new_row	Default: False	Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI	Default: True	Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
preforming_ramp_with_current_hold_time(device,start_voltage,ramp_speed_1,top_voltage,hold_time,ramp_speed_2,end_voltage,compliance_current=0,trigger_current=0,trigger_hold_time=0,new_row=False,GUI=True)
```

Return value are the following arrays: `[data_V_I,data_V_t,data_I_t]`

This function does a usual preforming as the *preformin_ramp* function with the additional possibility to add a certain trigger_current after which the function only runs for the amount of time specified in trigger_hold_time and then stops immediately even if the hold_time is set for some longer time.

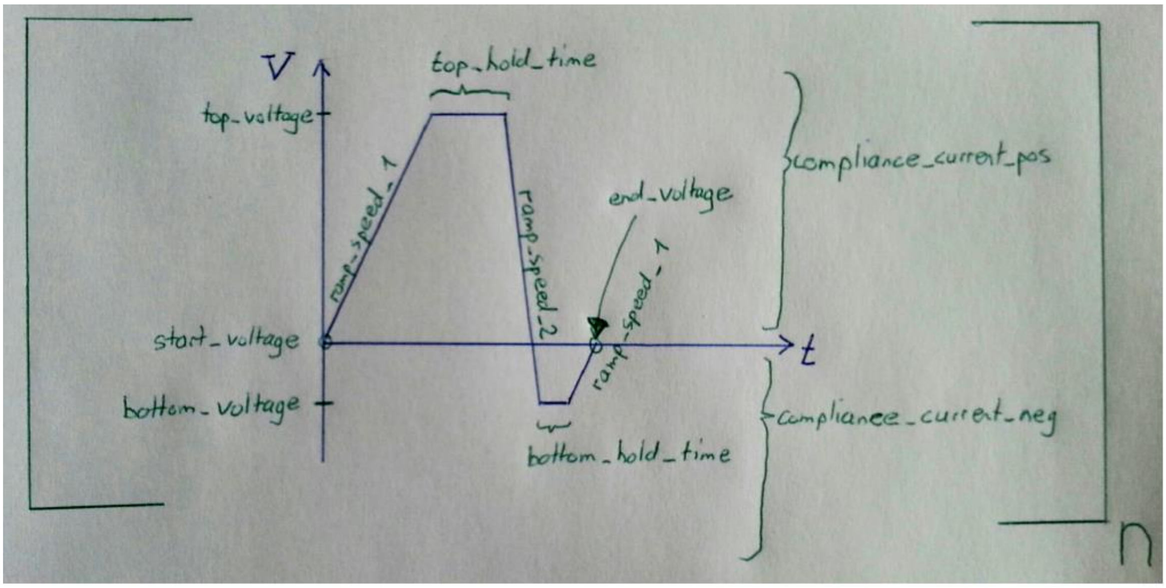
Argument	Unit	Remark
device		Pass the device you want to use for this function. To date only keithley_2601B, keithley_2602B and keithley_2612B and keithley_6517B can be used. Keep in mind that keithley_6517B has no compliance current capability.
start_voltage	V	Where you want to start
ramp_speed_1	V/s	
top_voltage	V	
hold_time	s	You can also set this to 0. Then it does not wait. In this case it does not make sense to set this value low since you usually want the current to rise over time till trigger_current is reached.
ramp_speed_2	V/s	Needs to be negative
end_voltage	V	You can also set this voltage equal to *bottom_voltage*. Then you only cycle in the positive branch
compliance_current	A	CC (Default=0 means no CC is applied)
trigger_current	A	(Default=0 means deactivated) After the here specified current has been reached (can be at any time), a second counter starts to run which will wait for *trigger_hold_time* seconds to stop the whole function
trigger_hold_time	s	(Default=0 means sudden stop after *trigger_current* has been reached). This variable states how many seconds the function should run more after *trigger_current* has been reached.
new_row	Default: False	Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI	Default: True	Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

Cyclic voltammetry

```
cycling(device,start_voltage,ramp_speed_1,top_voltage,top_hold_time,ramp_speed_2
,bottom_voltage,bottom_hold_time,end_voltage,n,compliance_current_pos=0,complian
ce_current_neg=0,new_row=False, GUI=True)
```

Return value are the following arrays: `[data_V_I,data_V_t,data_I_t]`

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date only keithley_2601B, keithley_2602B and keithley_2612B and keithley_6517B can be used. Keep in mind that keithley_6517B has no compliance current capability.
start_voltage	V	Where you want to start
ramp_speed_1	V/s	
top_voltage	V	
top_hold_time	s	You can also set this to 0. Then it does not wait
ramp_speed_2	V/s	Needs to be negative
bottom_voltage	V	You can also set this voltage equal to *end_voltage*. Then you only cycle in the positive branch
bottom_hold_time	s	You can also set this to 0. Then it does not wait
end_voltage	V	You can also set this voltage equal to *bottom_voltage*. Then you only cycle in the positive branch
n		Number of cycles you want to run
compliance_current_pos	A	CC in positive branch. Needs to be positive
compliance_current_neg	A	CC in negative branch. Needs to be positive
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.



```
cycling_two_channels(device,start_voltage_1,start_voltage_2,ramp_speed_1_1,ramp_speed_1_2,top_voltage_1,top_voltage_2,top_hold_time_1,top_hold_time_2,ramp_speed_2_1,ramp_speed_2_2,bottom_voltage_1,bottom_voltage_2,bottom_hold_time_1,bottom_hold_time_2,end_voltage_1,end_voltage_2,n_1,n_2,compliance_current_pos_1=0,compliance_current_pos_2=0,compliance_current_neg_1=0,compliance_current_neg_2=0,new_row=False,GUI=True)
```

Return value are the following arrays:
`[data_V_I_1,data_V_t_1,data_I_t_1,data_V_I_2,data_V_t_2,data_I_t_2]`

Blue is for **Channel A** and Green for **Channel B**

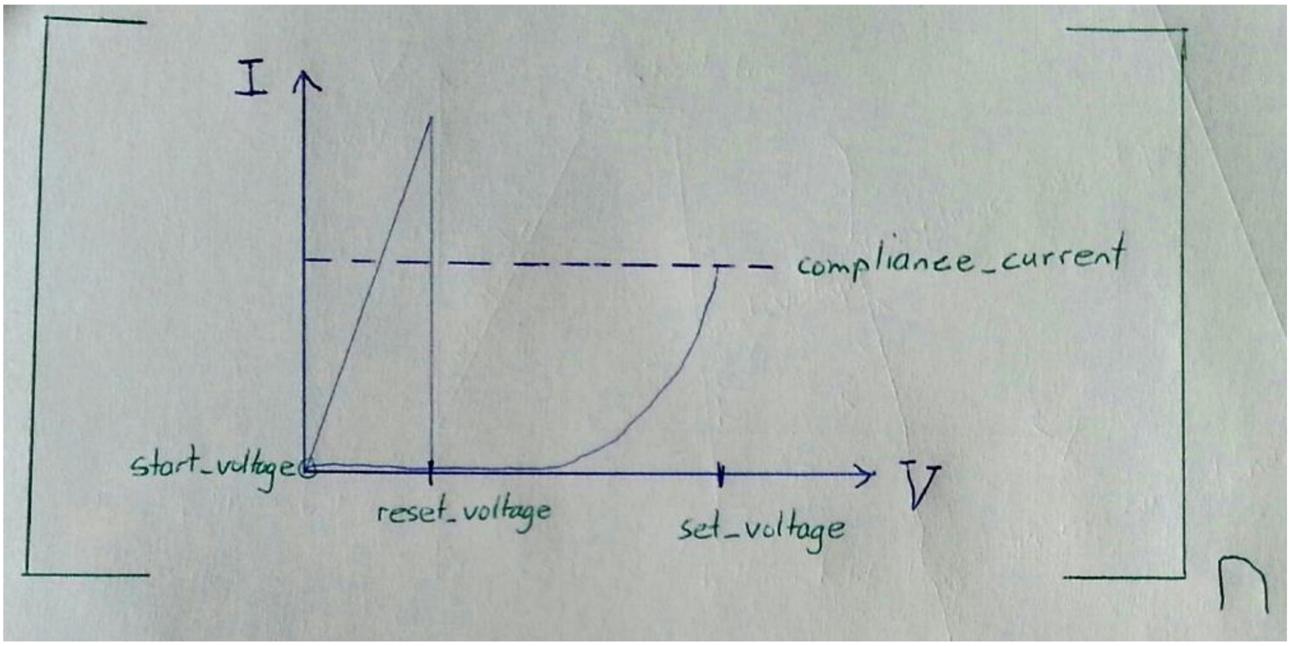
Argument	Unit	Remark
device		Pass the device you want to use for this function. To date only keithley_2602B and keithley_2612B can be used.
start_voltage_1	V	Where you want to start
ramp_speed_1_1	V/s	
top_voltage_1	V	
top_hold_time_1	s	You can also set this to 0. Then it does not wait
ramp_speed_2_1	V/s	Needs to be negative
bottom_voltage_1	V	You can also set this voltage equal to *end_voltage*. Then you only cycle in the positive branch
bottom_hold_time_1	s	You can also set this to 0. Then it does not wait
end_voltage_1	V	You can also set this voltage equal to *bottom_voltage*. Then you only cycle in the positive branch
n_1		Number of cycles you want to run
compliance_current_pos_1	A	CC in positive branch. Needs to be positive
compliance_current_neg_1	A	CC in negative branch. Needs to be positive
start_voltage_2	V	Where you want to start
ramp_speed_1_2	V/s	
top_voltage_2	V	
top_hold_time_2	s	You can also set this to 0. Then it does not wait
ramp_speed_2_2	V/s	Needs to be negative
bottom_voltage_2	V	You can also set this voltage equal to *end_voltage*. Then you only cycle in the positive branch
bottom_hold_time_2	s	You can also set this to 0. Then it does not wait
end_voltage_2	V	You can also set this voltage equal to *bottom_voltage*. Then you only cycle in the positive branch
n_2		Number of cycles you want to run
compliance_current_pos_2	A	CC in positive branch. Needs to be positive
compliance_current_neg_2	A	CC in negative branch. Needs to be positive
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

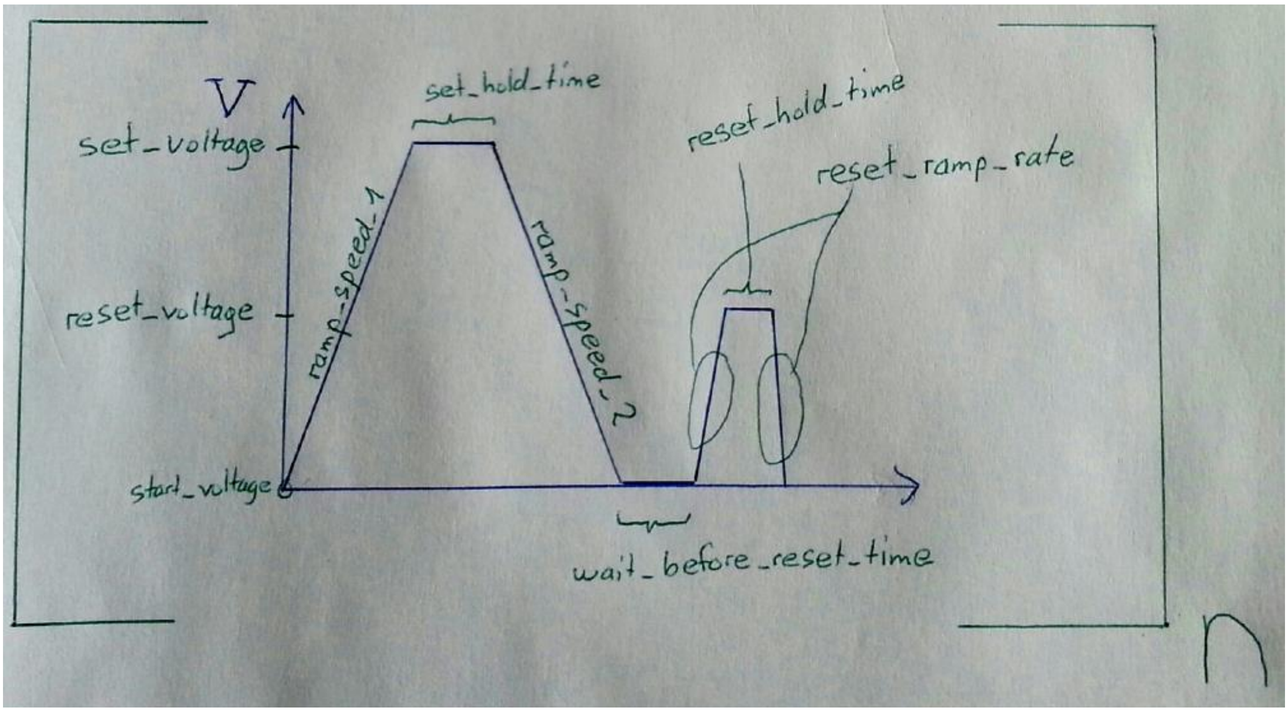
```
cycling_unipolar(device,start_voltage,ramp_speed_1,set_voltage,set_hold_time,com
pliance_current,ramp_speed_2,wait_before_reset_time,reset_voltage,reset_ramp_rat
e,reset_hold_time,n,new_row=False, GUI=True)
```

Return value are the following arrays: `[data_V_I,data_V_t,data_I_t]`

This function is optimized to test memristors for unipolarity. In normal cycling a compliance current is either applied globally or not at all. It is therefore possible, that unipolar switching behavior can not be asessed

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date only keithley_2601B, keithley_2602B and keithley_2612B can be used.
start_voltage	V	Where you want to start
ramp_speed_1	V/s	
set_voltage	V	
set_hold_time	s	You can also set this to 0. Then it does not wait
compliance_current	A	
ramp_speed_2	V/s	Needs to be negative
wait_before_reset_time	s	You can also set this to 0. Then it does not wait
reset_voltage	V	
reset_ramp_rate	V/s	This ramp rate is applied to both. Reset-ramp-up and reset-ramp-down
reset_hold_time	s	You can also set this to 0. Then it does not wait
n		Number of cycles you want to run
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.





V
set_hold_time
set_voltage
reset_voltage
start_voltage
ramp_speed_1
ramp_speed_2
reset_hold_time
reset_ramp_rate
wait_before_reset_time
n

```
cycling_current(device,start,ramp_speed_1,top,top_hold_time,ramp_speed_2,bottom,bottom_hold_time,end,n,maximum_voltage,new_row=False,GUI=True)
```

Return value are the following arrays: `[data_V_I,data_V_t,data_I_t]`

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date only keithley_2601B, keithley_2602B and keithley_2612B can be used. Keep in mind that **keithley_6517B DOES NOT WORK** for this function as it has no compliance current capability.
start	A	The applied current with which you want to start
ramp_speed_1	A/s	
top	A	The top current you want to reach. (However you have no influence if your device will be conductive enough to ever exactly reach that point.)
top_hold_time	s	You can also set this to 0. Then it does not wait
ramp_speed_2	A/s	Needs to be negative
bottom	A	You can also set this current equal to *end*. Then you only cycle in the positive branch
bottom_hold_time	s	You can also set this to 0. Then it does not wait
end	A	You can also set this voltage equal to *bottom*. Then you only cycle in the positive branch
n		Number of cycles you want to run
maximum_voltage	V	The global maximum voltage you allow the device to apply in order to reach the beforehand specified ramps. Keep in mind that the device itself also has some limitations regarding this variable (mostly ether 40V or 200V depending on the device used)
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

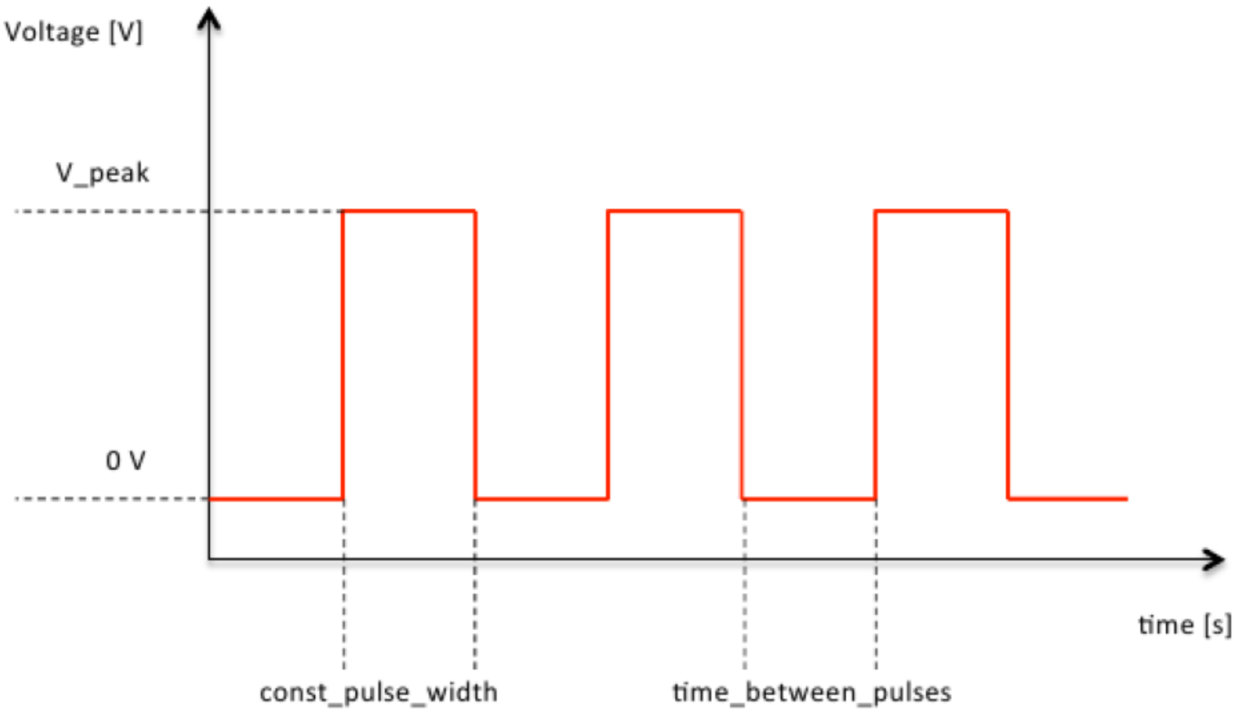
Pulsed experiments

```
pulse_rnone(device_smu,device_function_generator,V_peak,const_pulse_width,time_b
etween_pulses, num_pulses,new_row=False,GUI=True)
```

Return value are the following arrays:
`[data_V_t_2,data_I_t_2,data_cycle_R_2,data_cycle_post_R_2]`

This function just measures the current responce to a series of voltage pulses - there is no reading voltage and the currents starts and ends at zero voltage.

Argument	Unit	Remark
device_smu		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B can be used.
device_function_generator		Pass the device you want to use for this function. To date tektronix_AFG2021C and tektronix_AFG3021C can be used.
V_peak	V	Specifiy the peak voltage you want to be applied to the device.
const_pulse_width	s	Specify the with of the individual pulses
time_between_pulses	s	Specify the wait time between different pulses
num_pulses		How many pulses should be applied in total till the function ends
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

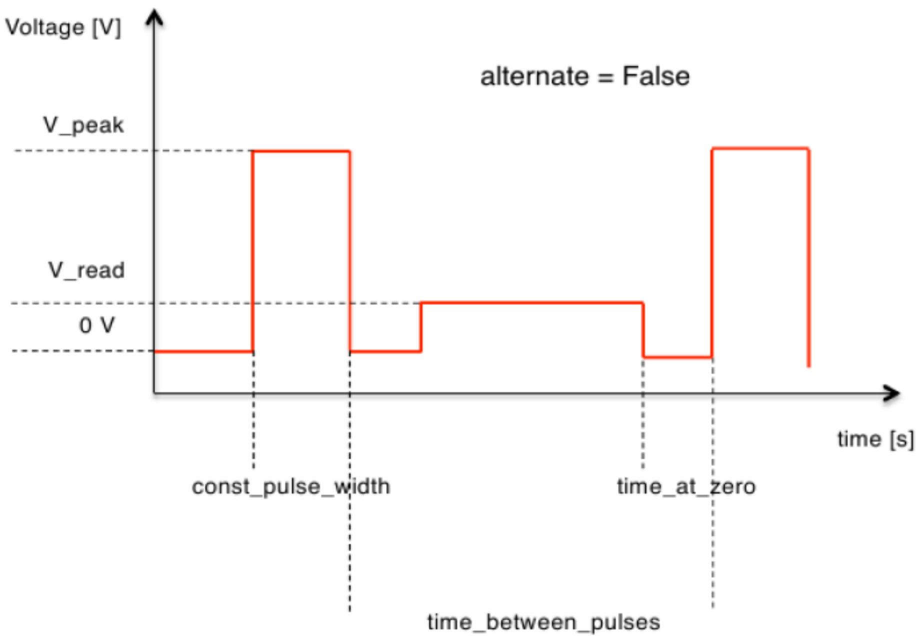


```
pulse_rsquare(device_smu,device_function_generator,V_peak,const_pulse_width,time
_between_pulses, num_pulses,time_at_zero,
V_read,alternate=True,new_row=False,GUI=True)
```

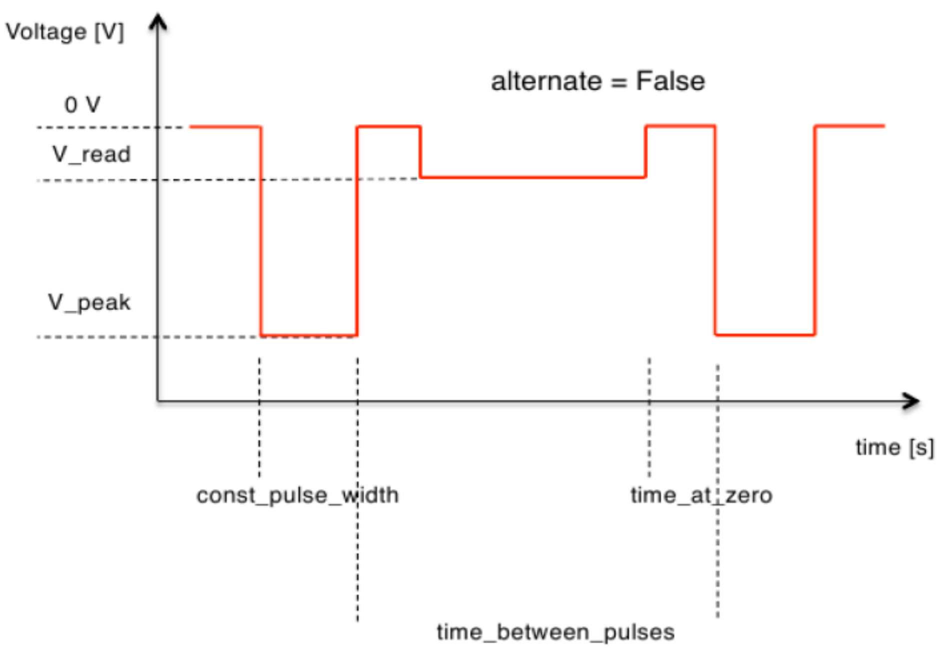
Return value are the following arrays:
`[data_V_t_2,data_I_t_2,data_cycle_R_2,data_cycle_post_R_2]`

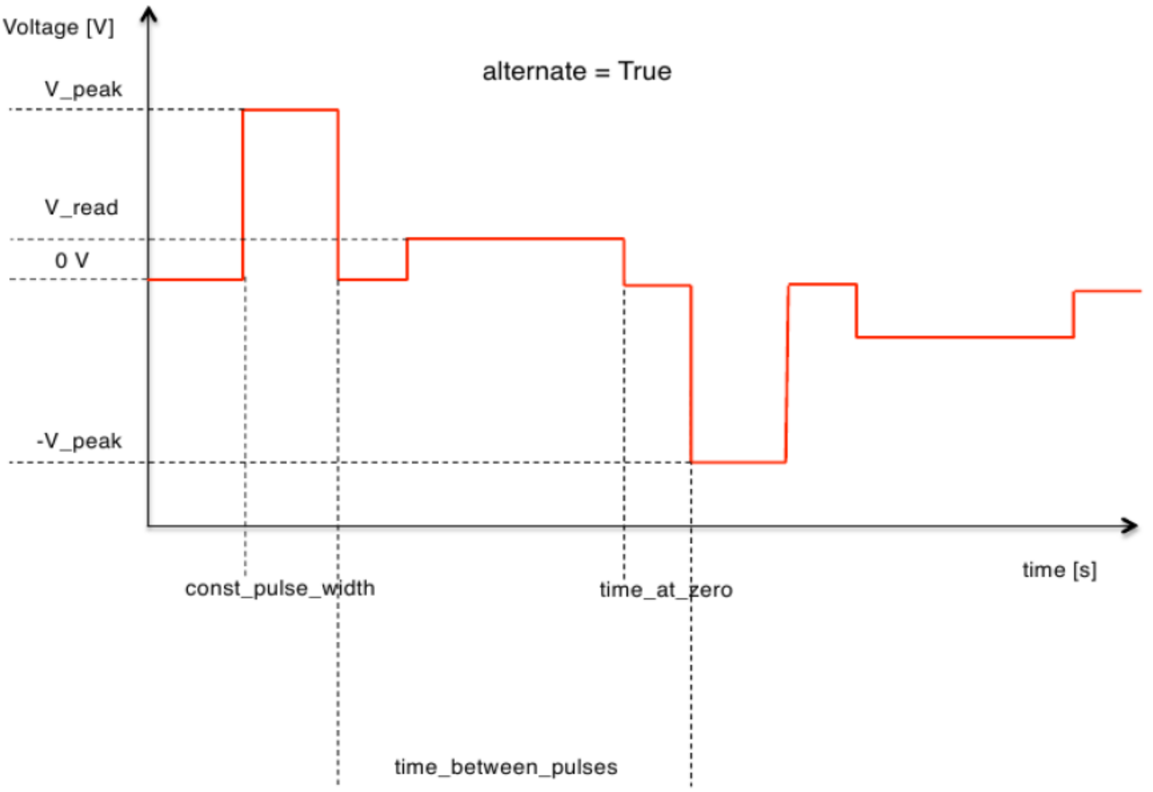
This function allows you to measure also the resistance during (depending on the time scale) and between pulses. - that means that there is a square reading scheme between the pulses.

Argument	Unit	Remark
device_smu		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B can be used.
device_function_generator		Pass the device you want to use for this function. To date tektronix_AFG2021C and tektronix_AFG3021C can be used.
V_peak	V	Specifiy the peak voltage you want to be applied to the device.
const_pulse_width	s	Specify the with of the individual pulses
time_between_pulses	s	Specify the wait time between different pulses
num_pulses		How many pulses should be applied in total till the function ends
time_at_zero	s	How long should the system remain at 0V
V_read	V	Specify the read voltage
alternate	Default: True	Either **True** or **False** If set to True, every 2nd pulse has opposite polarity
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent" measurements without real-time graphical output.



In case you put a negative V_peak voltage into the pulse_rsquare function then the reading voltage becomes automatically also negative. This is due to voltage spikes occurring when changing voltage polarity.





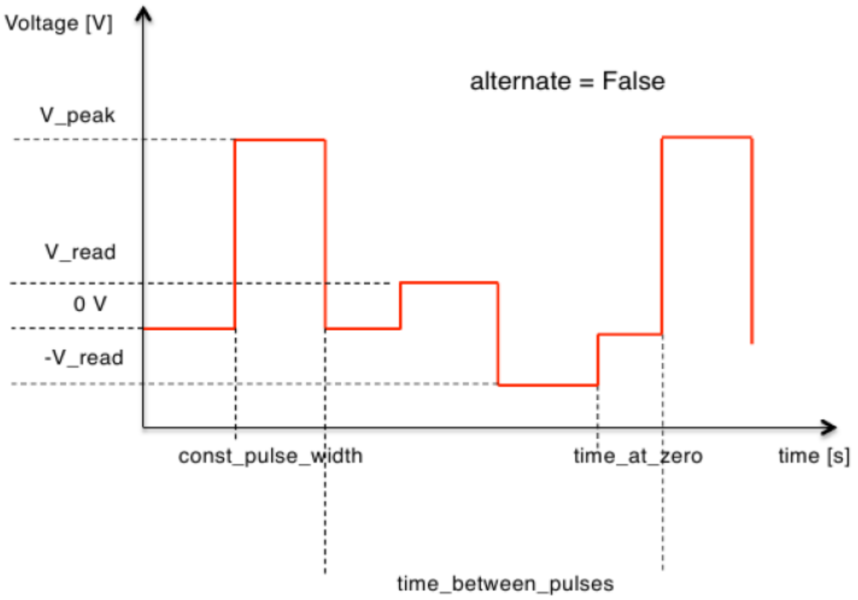
```
pulse_rbipolar(device_smu,device_function_generator,V_peak,const_pulse_width,tim
e_between_pulses, num_pulses,time_at_zero, V_read, alternate=True,
new_row=False,GUI=True)
```

Return value are the following arrays:

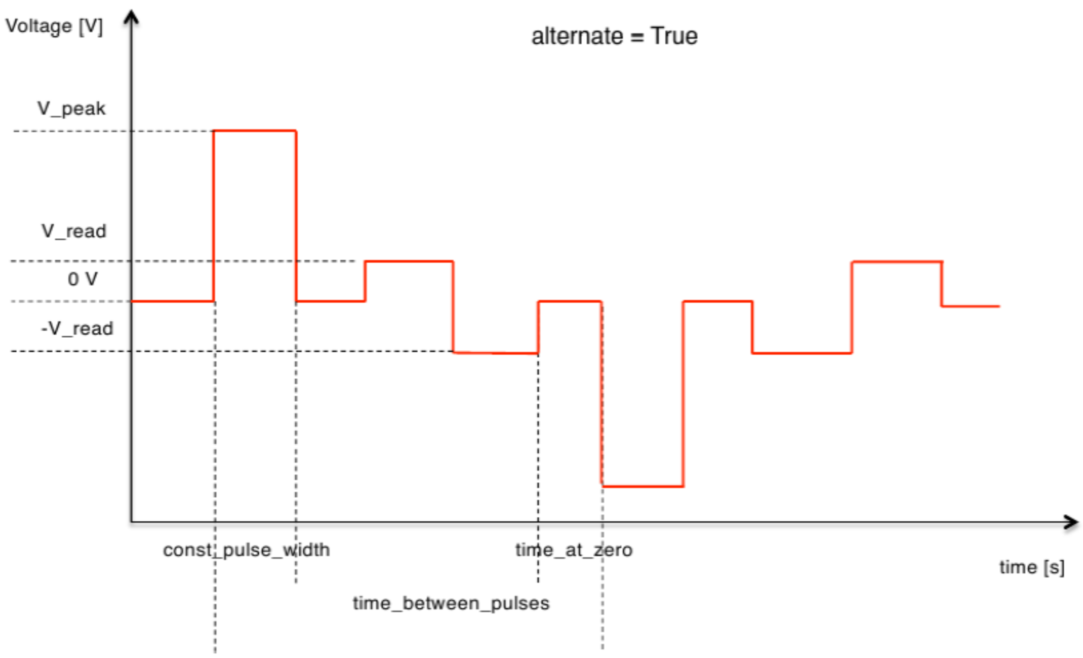
```
[data_V_t_2,data_I_t_2,data_cycle_R_2,data_cycle_post_R_2_plus,
data_cycle_post_R_2_minus]
```

This function allows you to measure also the resistance during (depending on the time scale) and between pulses. There is a bipolar pulse reading scheme between the pulses. This is an advantage over a constant reading scheme since the device will not be disturbed. No resistence will be measured during the time at zero. This is just an option to leave the current to equilibrate.

Argument	Unit	Remark
device_smu		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B can be used.
device_function_generator		Pass the device you want to use for this function. To date tektronix_AFG2021C and tektronix_AFG3021C can be used.
V_peak	V	Specifiy the peak voltage you want to be applied to the device.
const_pulse_width	s	Specify the with of the individual pulses
time_between_pulses	s	Specify the wait time between different pulses
num_pulses		How many pulses should be applied in total till the function ends
time_at_zero	s	How long should the system remain at 0V
V_read	V	Specify the read voltage
alternate	Default: True	Either **True** or **False** If set to True, every 2nd pulse has opposite polarity
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.



The bipolar read between the pulses ensures that no memristance change occurs during the reading process (a change during a positive reading pulse will be reversed with a negative reading pulse). Is a good choice for sensitive devices or higher reading voltages.



Simple loggers

Those functions are kept very simple for the case one just needs to monitor some measurement without further requirements.

```
voltage_logger(device,total_measurement_time,bias_current=0,new_row=False,
GUI=True)
```

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B, keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
total_measurement_time	s	How long you want to log the voltage
bias_current	A	Specifiy the bias current you want to be applied to the device. Default = 0 means no bias at all
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
current_logger(device,total_measurement_time,bias_voltage=0,new_row=False,
GUI=True)
```

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B, keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
total_measurement_time	s	How long you want to log the voltage
bias_voltage	V	Specifiy the bias voltage you want to be applied to the device. Default = 0 means no bias at all
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
resistance_2w_logger(device,total_measurement_time,new_row=False, GUI=True)
```

Measures resistance with 2-wire setup

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B, keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
total_measurement_time	s	How long you want to log the voltage
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
resistance_4w_logger(device,total_measurement_time,new_row=False, GUI=True)
```

Measures resistance with 4-wire setup

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B, keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
total_measurement_time	s	How long you want to log the voltage
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
temperature_logger(device,total_measurement_time,sensor="K",num_of_channels=1,new_row=False, GUI=True)
```

Argument	Unit	Remark
device		Pass the device you want to use for this function. To date keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
total_measurement_time	s	How long you want to log the voltage
sensor	Default: K	Specify which type of thermocouple you will be using. Choose from J,T,S,E,R,B,N,K
num_of_channels	Default: 1	Which channels do you want to use. (Not working at the moment)
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
temperature_current_logger(device_temperature,device_smu,total_measurement_time,
bias_voltage,sensor="K",new_row=False, GUI=True)
```

Argument	Unit	Remark
device_temperature		Pass the device you want to use for this function. To date keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
device_smu		Pass the SMU device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B can be used.
total_measurement_time	s	How long you want to log the voltage
bias_voltage	V	Put the voltage value the SMU should source during the experiment.
sensor	Default: K	Specify which type of thermocouple you will be using. Choose from J,T,S,E,R,B,N,K
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

Oven control programs

```
sintering(device_temperature,device_oven,temperature_values,ramp_rate,stabilizat
ion_time,sensor="K",GUI=True)
```

Argument	Unit	Remark
device_temperature		Pass the device you want to use for this function. To date keithley_2601B, keithley_2612B, keithley_6517B, keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
device_oven		Pass the oven device you want to use for this function. To date eurotherm_2404, eurotherm_2416, eurotherm_3216 can be used.
temperature_values	°C	Can be a single value like 850 or an array of values like [200,400,600,800]. Then those values are all run to with the *ramp_rate* specified and hold for as long as *stabilization_time*
ramp_rates	K/min NOT SI unit	Set the ramp rate(s). Can be a single number or an array like [300,400,500]
stabilization_times	s	How long a temperature should be kept after having ramped to that value.
sensor	Default: K	Specify which type of thermocouple you will be using. Choose from J,T,S,E,R,B,N,K
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
arrhenius_dc(device_temperature,device_smu,device_oven,temperature_values,ramp_rates,stabilization_times,voltage_values,measurement_time=60,continuous_voltage=True,GUI=True)
```

Return value are the following arrays: `[data_T_t,data_P_t,data_I_t,data_R_T]`

Argument	Unit	Remark
device_temperature		Pass the device you want to use for this function. To date keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
device_smu		Pass the SMU device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B, keithley_6517B can be used.
device_oven		Pass the oven device you want to use for this function. To date eurotherm_2404, eurotherm_2416, eurotherm_3216 can be used.
temperature_values	°C	Can be a single value like 850 or an array of values like [200,400,600,800]. Then those values are all run to with the *ramp_rate* specified and hold for as long as *stabilization_time*
ramp_rates	K/min NOT SI unit	Set the ramp rate(s). Can be a single number or an array like [300,400,500]
stabilization_times	s	How long a temperature should be kept after having ramped to that value.
voltage_values	V	[Array] or single number of voltage value(s) you want to apply to the device at each temperature specified under temperature_values.
measurement_time	s	How many seconds you want to perform the actual measurement per each voltage specified. Default is 60 sec
continuous_voltage	Default: True	Specify if you want the voltage to be applied during the whole time (also while ramping) or just after the stabilization for the time specified in measurement_time. If set to True, the variable voltage_values cannot be an array but just a single value.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

```
arrhenius_ac(device_temperature,device_oven,device_impedance,temperature_values,
ramp_rates,stabilization_times,number_of_repetitions=1,start_frequency=0.1,end_f
requency=1.0e6,ac_amplitude=0.1,bias=0,num_points_per_decade=10,path="/home/elec
trochem/lost_data",GUI=True)
```

There is no return value to this function since the whole data gets already safed to a file specified.

Argument	Unit	Remark
device_temperature		Pass the device you want to use for this function. To date keithley_2000, keithley_2001, keithley_2700, keithley_2182A can be used.
device_oven		Pass the oven device you want to use for this function. To date eurotherm_2404, eurotherm_2416, eurotherm_3216 can be used.
device_impedance		Pass the impedance bridge device you want to use for this function. To date Zahner_IM6, Solartron or Gamry Reference 600 can be used.
temperature_values	°C	Can be a single value like 850 or an array of values like [200,400,600,800]. Then those values are all run to with the *ramp_rate* specified and hold for as long as *stabilization_time*
ramp_rates	K/min NOT SI unit	Set the ramp rate(s). Can be a single number or an array like [300,400,500]
stabilization_times	s	How long a temperature should be kept after having ramped to that value.
number_of_repetitions		Specify how many times the impedance measurement should be repeated to get better signal to noise. Default=1. This variable **should not be changed** at the moment since it produces unexpected result and does not work with all the impedance bridges so far! You have been warned!
start_frequency	Hz	Specify the lower frequency boundary at which your device should be measured. Default is 0.1 Hz. However the measurement not always starts at this frequency. This depends on the impedance bridge.
end_frequency	Hz	Specify the higher frequency boundary at which your device should be measured. Default is 1 MHz. However the measurement not always starts at this frequency. This depends on the impedance bridge. Much higher frequency usually don't make sense and you start measuring your not propperly setup cables.
ac_amplitude	V	Specify the voltage amplitude with which you want to excite your system. The higher the less noise but the more you also affect and change the system by measuring it. Default is 0.1V
bias	V	Specify a bias voltage during impedance measurement to better separate electrode contributions. Default is no bias
num_points_per_decade		How many datapoints should be measured on your final logarithmic impedance plot. Default is 10 and mostly sufficient to fit the data.
path	Filepath	Specify a path to which you have write-access where the datafiles from the different spectra should be safed to. It is suggested to make a new folder somewhere in the umdata path. Default is */home/electrochem/lost_data*
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

Impedance measurement

```
impedance(device_impedance, start_frequency, end_frequency, ac_amplitude=0.05, bias=0, num_points_per_decade=10, new_row=False, GUI=True)
```

Return value are the following arrays:

```
[data_Zi_Zr,data_freq_mod,data_bias_ampl_time_range_err_temp]
```

Argument	Unit	Remark
device_impedance		Pass the impedance bridge device you want to use for this function. To date Zahner_IM6, Solartron or Gamry Reference 600 can be used.
start_frequency	Hz	Specify the lower frequency boundary at which your device should be measured. Default is 0.1 Hz. However the measurement not always starts at this frequency. This depends on the impedance bridge.
end_frequency	Hz	Specify the higher frequency boundary at which your device should be measured. Default is 1 MHz. However the measurement not always starts at this frequency. This depends on the impedance bridge. Much higher frequency usually don't make sense and you start measuring your not propperly setup cables.
ac_amplitude	V	Specify the voltage amplitude with which you want to excite your system. The higher the less noise but the more you also affect and change the system by measuring it. Default is 0.1V
bias	V	Specify a bias voltage during impedance measurement to better separate electrode contributions. Default is no bias
num_points_per_decade		How many datapoints should be measured on your final logarithmic impedance plot. Default is 10 and mostly sufficient to fit the data.
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

Mass flow controller

`mfc(device_mfc,stabilization_times,flow_rates,GUI=True)`

Return value are the following arrays: `[data_F_t,data_FP_t]`

Pass the following device to this function as an example:

`voegtlin_gsc = voegtlin_gsc("/dev/ttyUSB0",[12,3])`

The first argument "/dev/ttyUSB0" is the corresponding USB port on that Linux-machine, and the array [12,3] specifies that the Modbus-Addresses 12 and 3 are used by the devices we want to communicate with.

Argument	Unit	Remark
device_mfc		Pass the mass flow controller device you want to use for this function. To date only voegtlin_gsc can be used.
stabilization_times	s	Specify the time a certain flow should be kept in each step. You can either use a scalar if you only have one stabilization time or an array if you have multiple.
flow_rates	[string or modbus-address, sccm]	Specify for each stabilization step, which flowmeters should have which set-flow. Use a 3d-array for multiple flowmeters at multiple steps. See below for more information.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent" measurements without real-time graphical output.

<u>flow_rates example:</u>

You can specify this array in 3 different ways.
It can be in the following manner

[[["gastype1" or modbusnumber , set_flow],[...]] , [...]]

for example: `[[["Air 5000",1000],["N2 300",50]],[["Air 5000",500],["N2 300",150]]]`
Assuming you have two stabilization times, this will set Air-flow to 1000 sccm and N2 to 50 sccm in the first step and Air-flow to 500 sccm and N2 to 150 sccm in the second step.

or if only one gas used:
[["gastype1" or modbusnumber , set_flow] , [...]]

for example: `[["Air 5000",1000],["Air 5000",700],["Air 5000",100]]`
Assuming you have 3 stabilization times, this will set Air-flow to 1000 sccm in the first step to 700 sccm in the second step and finally to 100 in the 3rd step.

or if only one gas and one flow used:
["gastype1" or modbusnumber , set_flow]
for example: `["Air 5000",1000]` In this case during all step 1000sccm Air will be used

Galvanostatic cycling

```
galvanostatic_cycling(device_smu,current_1,target_voltage_1,hold_time_1,hold_cur
rent_1,current_2,target_voltage_2,hold_time_2,hold_current_2,n=1,ocv_measurement
_time=0,set_I_zero_after_cycle=False,new_row=False,GUI=True)
```

Return value are the following arrays: `[data_0,data_1,data_2,data_3]`

Argument	Unit	Remark
device_smu		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B can be used.
current_1	A	Specify the constant current which should be applied in the first stage of either charge or discharge. (Note: different currents can be set for charge and discharge)
target_voltage_1	V	Specify the voltage to which the cell should be charged or discharged
hold_time_1	s	Time to stay at target_voltage_1 after reaching it
hold_current_1	A	Wait at target_voltage_1 until the current drops to this value or hold_time_1 is over, whatever condition comes first.
current_2	A	Specify the constant current which should be applied in the second stage of either charge or discharge. (Note: different currents can be set for charge and discharge)
target_voltage_2	V	Specify the voltage to which the cell should be charged or discharged
hold_time_2	s	Time to stay at target_voltage_2 after reaching it
hold_current_2	A	Wait at target_voltage_2 until the current drops to this value or hold_time_2 is over, whatever condition comes first.
n		Number of cycles the cell should be tested for. (Can be an array for rate capability testing)
ocv_measurement_time	s	How long the open circuit voltage should be measured prior to any cycling
Set_I_zero_after_cycle		Disconnects the electrochemical cell galvanically from the measurement device after the cycle
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

<u>Galvanostatic cycling examples:</u>

You can specify arrays for the purpose of rate capability testing.

```
galvanostatic_cycling(device_smu,[10e-9,100e-9,10e-9], 4.1,0,0,[-10e-9,-100e-9,-
10e-9], 1.1,0,0,n=[10,5,10], ocv_measurement_time=60)
```

this example: will perform 10 cycles at 10 nA of current followed by 5 cycles at 100 nA and then go back to 10 cycles at 10 nA. OCV is measured for 1 minute and the cycling range is between 1.1 Volts and 4.1 Volts.

High precision galvanostatic cycling

This function is intended to be used in combination with a high precision current source such as Keithley 6220 series in order to cycle under most stable low currents. Note that the function is similar to the previous description, but a second device file (the current source) has to be provided in addition. The current source is exclusively dedicated to providing stable ultra-low currents.

```
galvanostatic_cycling_nano(device_voltmeter,device_current_source,current_1,target_voltage_1,hold_time_1,hold_current_1,current_2,target_voltage_2,hold_time_2,hold_current_2,n=1,ocv_measurement_time=0,set_I_zero_after_cycle=False,new_row=False,GUI=True)
```

Return value are the following arrays: `[data_0,data_1,data_2,data_3]`

Argument	Unit	Remark
device_smu		Pass the device you want to use for this function. To date keithley_2601B, keithley_2602B, keithley_2612B can be used.
device_current_source		Pass the device you want to use for ultra-low high precision current to be sourced. To date only keithley_6220 can be used.
current_1	A	Specify the constant current which should be applied in the first stage of either charge or discharge. (Note: different currents can be set for charge and discharge)
target_voltage_1	V	Specify the voltage to which the cell should be charged or discharged
hold_time_1	s	Time to stay at target_voltage_1 after reaching it
hold_current_1	A	Wait at target_voltage_1 until the current drops to this value or hold_time_1 is over, whatever condition comes first.
current_2	A	Specify the constant current which should be applied in the second stage of either charge or discharge. (Note: different currents can be set for charge and discharge)
target_voltage_2	V	Specify the voltage to which the cell should be charged or discharged
hold_time_2	s	Time to stay at target_voltage_2 after reaching it
hold_current_2	A	Wait at target_voltage_2 until the current drops to this value or hold_time_2 is over, whatever condition comes first.
n		Number of cycles the cell should be tested for. (Can be an array for rate capability testing)
ocv_measurement_time	s	How long the open circuit voltage should be measured prior to any cycling
Set_I_zero_after_cycle		Disconnects the electrochemical cell galvanically from the measurement device after the cycle
new_row		Either **True** or **False** If set to True, the plotting window will make a new row and the display looks nicer.
GUI		Either **True** or **False** If set to False, the plotting window will not appear at all. Can be used for „silent“ measurements without real-time graphical output.

Galvanostatic cycling examples:

```
galvanostatic_cycling_nano(device_smu, device_current_source, 10e-9, 4.2,0,0,-
10e-9, 1.1,0,0,n=100, ocv_measurement_time=120)
```

this example: will perform 100 cycles at 10 nA of current. OCV is measured for 2 minute and the cycling range is between 1.1 Volts and 4.2 Volts.

You can specify arrays for the purpose of rate capability testing.

```
galvanostatic_cycling_nano(device_smu, device_current_source, [10e-9,100e-9,10e-
9], 4.1,0,0,[-10e-9,-100e-9,-10e-9], 1.1,0,0,n=[10,5,10],
ocv_measurement_time=60)
```

this example: will perform 10 cycles at 10 nA of current followed by 5 cycles at 100 nA and then go back to 10 cycles at 10 nA. OCV is measured for 1 minute and the cycling range is between 1.1 Volts and 4.1 Volts.