

# Low-Level Pulsed Electrical Characterization with the Model 6221/2182A Combination

## Introduction

Low-level electrical measurements are performed on components and materials to characterize their electrical properties. The two most common tests measure resistance (R) and I-V characteristics. Some devices require low current levels because the operating currents are low and require low current I-V and R characterization to avoid damaging or altering the devices during test. When measuring small devices, introducing even tiny amounts of heat to the device under test can raise its temperature, skewing test results or even destroying the device.

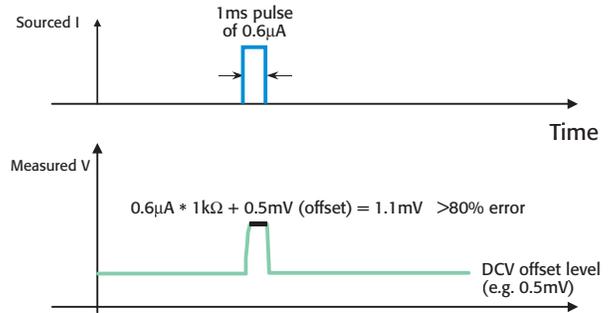
When the device power limitations prevent electrical characterization at the intended operating levels of the component, then pulsed testing is needed. For example, during testing prior to packaging, many devices can't tolerate the level of power they will experience in normal use because they lack the heat sinking the packaging provides, but testing is still necessary.

This application note describes how to use the Keithley Model 6221 Precision AC/DC Current Source together with the Model 2182A Nanovoltmeter to perform low-level pulsed electrical characterization on devices where continuous DC characterization is not possible. When used with the Model 2182A, the Model 6221's pulse capability minimizes the amount of power dissipated in a device. The Model 6221/2182A combination synchronizes the pulse and measurement so a measurement can begin as soon as  $16\mu\text{s}$  after the pulse is applied. (See *Figure 7*.) The entire pulse, including a complete nanovolt measurement, can be as short as  $50\mu\text{s}$ .

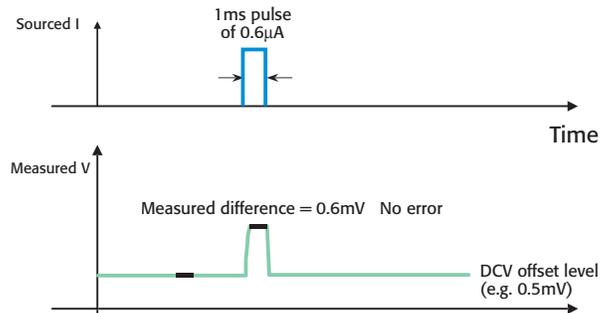
## Test Description

Low-level pulsed measurements involve sourcing a pulse of current and measuring the resulting voltage. Because the Model 6221/2182A combination is intended for pulse characterization at low signal levels, low-level noise issues will be of concern. However, the 6221/2182A combination differs from all previous test configurations in some important ways. One of the differences is that all of the pulse measurements are difference (or relative) measurements. This means that background voltages that would add error to the measured signal, such as offsets, drift, noise, and thermoelectric EMFs, are cancelled. (See *Figure 1a*.)

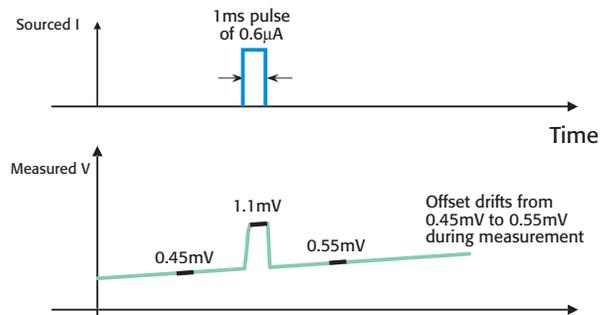
Offsets are cancelled using a delta-mode measuring technique. (See *Figure 1b*.) A two-point delta mode measurement works by sourcing current pulses and taking one measurement before and one during each pulse. Taking the difference between these two measurements cancels out any constant



**Figure 1a:** DC offsets due to thermal voltages and meter offsets can give significant errors in the measured voltage.



**Figure 1b:** Performing relative measurements cancels offset error. The measured delta voltage gives correct voltage response to the current pulse.



**Figure 1c:** An optional third measurement point can help cancel moving offsets.

thermoelectric offsets, which leaves the true value of the voltage. However, the two-point method cannot cancel thermoelectric offsets that drift over time. Using a third measuring point in the delta method cancels drifting offsets. (See *Figure 1c*.)

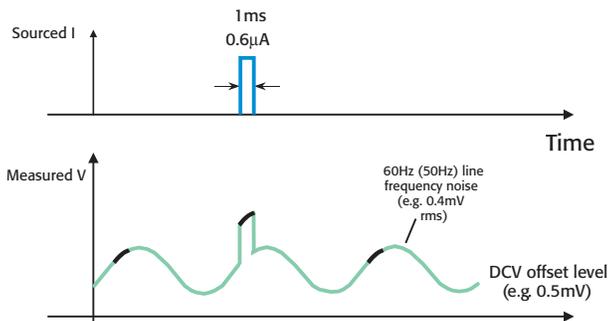
The third measurement is optional because it is not always preferable. For instance, depending on the device timing characteristic, if the sourced current pulse has long-lasting effects on the device, the third measured point, which is intended for

canceling the moving offset, may include errors due to the heat from the pulse of the DUT and, therefore, do more harm than good. (See *Figure 2*.)



**Figure 2.** Heat generated by the pulse in the DUT or contacts may corrupt the third measured point, so it may be discarded.

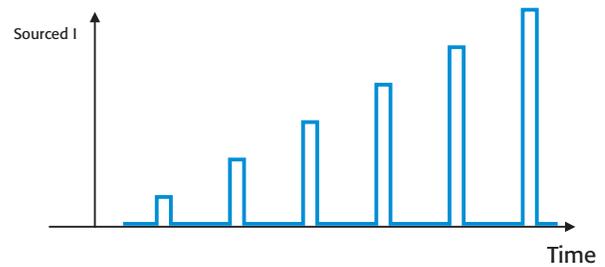
The other way in which the 6220/2182A combination differs from other pulsed testing solutions is that all the pulse measurements are line synchronized. The synchronization cancels all line frequency related noise. (See *Figure 3*.) Power line noise can compromise measurement accuracy significantly at low-level voltages. By synchronizing the measurement cycle to the line, interference is reduced, typically 55 to 75dB. It also minimizes variations due to readings that begin at different phases of the line cycle. The result is high immunity to line interference with little or no shielding or filtering required.



**Figure 3:** Operating at low voltage levels, measurements are susceptible to line frequency interference. Using line synchronization eliminates line frequency noise.

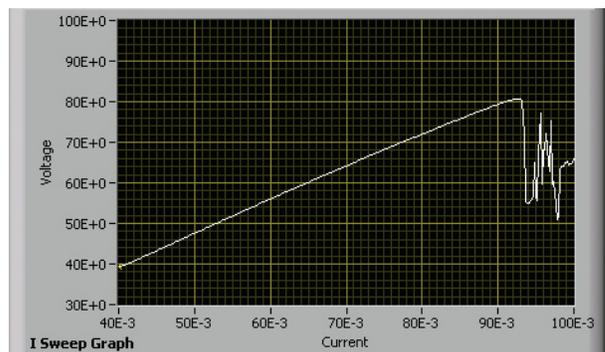
Performing pulsed measurements means using shorter measurement times, which has the potential to lead to noisier results. To reduce noise without increasing pulse width, it's possible to repeat the pulse several times and average the results. The 6221/2182A combination performs this averaging (filtering) automatically with any number of pulses up to 300. This method reduces noise by a factor of  $\sqrt{N}$ , where N is the number of pulses to be averaged.

One common reason for performing pulsed measurements is to reduce power while performing an I-V sweep. Each step of the I-V sweep is performed as a pulse. The 6221/2182A allows sweeps with linear or logarithmic (exponential) steps. *Figure 4* shows how the sourced current can be ramped in a linear pulse sweep. All of the advantages of line synchronization and delta technique also apply to these pulse sweeps.

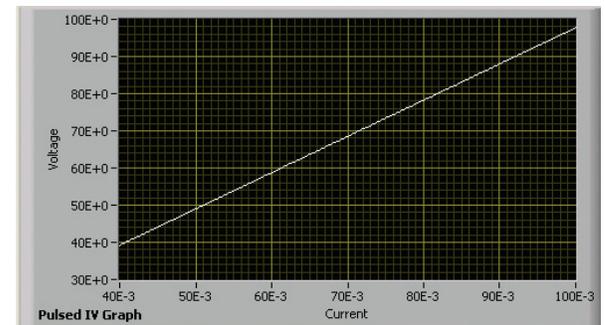


**Figure 4:** A series of pulses increasing in amplitude.

*Figure 5* shows I-V curves measured on identical devices. In *Figure 5a*, a DC I-V curve heats up the device, altering the I-V curve, and finally results in device failure. Using a pulsed I-V technique, *Figure 5b* shows that the same range of currents and voltages can be characterized, with no effect from device heating.

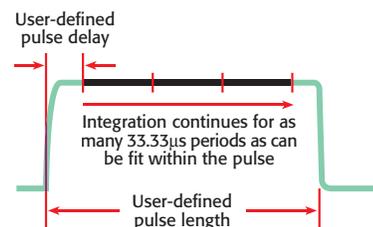


**Figure 5a:** DC I-V curve from 40mA to 100mA. Testing destroys the DUT.



**Figure 5b:** Pulsed I-V curve over the same range.

To maximize observation time during the pulse, the 2182A's A/D converter will integrate continuously from the end of the user programmed delay, until the end of the pulse, as shown in *Figure 6*. The integration time is quantized into 33.33µs increments, so the integration may end as much as 33µs before the end of the pulse.



**Figure 6.** Measurement integration time is automatically maximized.

## Test System and Configuration

These are some commands to set the Model 6221/2182A up for pulse testing:

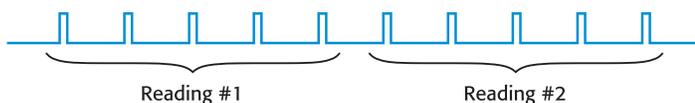
### Repetitive pulsed test



In this example, we want to do a repetitive pulsed test, pulsing 10mA, with a pulse width of 100 $\mu$ s, repeating ten times per second. Assume that to accommodate device settling time, we want to wait 60 $\mu$ s after the beginning of the pulse before we make the voltage measurement. If the device is a 0.5 $\Omega$  resistor, the pulse would generate 5mV across the device during the pulse.

| Program Code                                 | Key Sequence                                     | Comments  |
|--|--|---|
| *rst   | SETUP *RST                                       | Reset to a known state  |
| Program a 0.5s delay                         |  | Wait for reset  |
| pdel:high 0.01                               | CONFIG→PULSE→I-HI 10mA                           | Set pulse to 10mA   |
| pdel:coun INF                                | CONF→PULSE→COUNT→INFINITE                        | Pulse continuously (stores up to 65536)                                 |
| pdel:widt 0.0001                             | CONF→PULSE→WIDTH 0.1ms                           | 100 $\mu$ s pulse width   |
| pdel:sdel 6e-5                               | CONF→PULSE→SRC-DEL 0.06ms                        | 60 $\mu$ s pulse delay  |
| pdel:int 6                                   | CONF→PULSE→INTRVL 6 PLC                          | Interval of 0.1s = 6 Power Line Cycles (5PLC if using 50Hz power)       |
| :syst:comm:ser: send ".sens:volt: rang 0.01" | Press ▲/▼ arrows on 2182A to reach desired range | Set 2182A to 10mV range for best sensitivity on the 5mV expected signal |
| pdel:arm                                     | PULSE  | Arm the pulse mode  |
| Program a 3s delay                           |  | Wait for ARM  |
| :init:imm                                    | TRIG   | Begin pulsing   |

### Adding filtering



To add filtering, e.g. average blocks of five consecutive readings for a single result, add these before ARM:

| Program Code        | Key Sequence         | Comments   |
|---------------------|----------------------|--|
| :sens:aver:tcon REP | CONF→AVG→TYPE→REPEAT | repeat filter - store one value for every n pulses |
| :sens:aver:coun 5   | CONF→AVG→COUNT 5     | Set filter block size to 5 readings (Set n = 5)    |
| :sens:aver:stat ON  | AVG                  | Turn filter ON                                     |

## Sweeping pulse height logarithmically



To sweep the pulse height logarithmically from 10nA to 10mA, with each point 10 $\times$  larger than the last one, add these before the ARM command:

| Program Code             | Key Sequence                   | Comments  |
|--------------------------|--------------------------------|---|
| pdel:swe ON              | CONF→PULSE→SWEEP→YES           | Select sweep pulse mode   |
| swe:spac LOG             | CONF→SWP→TYPE→LOG              | Select logarithmic sweep spacing  |
| curr:start 1e-8          | START 10nA                     | Start at 10nA   |
| curr:stop 0.01           | STOP 10mA                      | Stop at 10mA  |
| curr:poin 7              | NO OF POINTS 7                 | 7 points (10nA,100nA,...,10mA)  |
| del 0.1                  | DELAY 0.1 s                    | Interval entered in seconds   |
| swe:rang AUTO            | CONF→ SWP→SOURCE-RANGING →AUTO | AUTO uses lowest range possible for each source value in the sweep          |
| :form:elem READ,TST,SOUR |                                | Only required when reading back over the bus. Thus, no front panel control. |
|                          |                                | Stores 3 elements: reading, timestamp and current for each pulse in a sweep |

## Sweeping pulse height linearly



To sweep the pulse height linearly from 0 to 10mA, in 100 steps, replace all but first and last commands above with these:

| Program Code                      | Key Sequence                   | Comments  |
|-----------------------------------|--------------------------------|---|
| swe:spac LIN                      | CONF→SWP→TYPE→STAIR            | Select linear sweep spacing                               |
| curr:start 0                      | START 0mA                      | Start at 0mA  |
| curr:stop 0.01                    | STOP 10mA                      | Stop at 10mA  |
| curr:poin 101 or curr:step 0.0001 | STEP 0.1mA                     | 101 points (0, 0.1mA,...,10mA)                            |
| del 0.1                           | DELAY 0.1 s                    | Interval entered in seconds                               |
| swe:rang BEST                     | CONF→ SWP→SOURCE-RANGING →AUTO | BEST uses lowest range which will handle all sweep values |

## Altering off state of the pulse

To alter the off state of the pulse, add the following before the ARM command. This can be used to adjust the off value closer to a true zero, to further reduce the power between pulses.

| Program Code   | Key Sequence          | Comments                               |
|----------------|-----------------------|--|
| pdel:low -1e-9 | CONF→PULSE→I-LOW -1nA | To subtract 1nA if there is 1nA offset |

## Omitting the zero-measurement

To omit the zero-measurement following the pulse, add this before the ARM command:

| Program Code | Key Sequence                    | Comments                               |
|--------------|---------------------------------|--|
| pdel:lme 1   | CONF→PULSE→LOW-MEAS 1-LOW/PULSE | Default is 2, one before and one after |

## Retrieving data

To read data back from the instrument (or view) even while pulsing continues:

| Program Code  | Key Sequence                                 | Comments  |
|---|--|---|
| :trac:data:sel? 0,1000                                    | RECALL→ Press ▲/▼ arrows to select reading # | Command fetches the first 1000 (max 65536) readings starting with #0                                  |
| ENTER 50000 bytes<br>Command varies with program language |  | Must read enough bytes from GPIB or Ethernet port:<br>1000points * 3 elements * 16 bytes/elem = 48000 |

## Equipment List

The following equipment is required to assemble a low-level pulsed electrical characterization system:

- 1) Keithley Model 6221 AC/DC Precision Current Source
- 2) Keithley Model 2182A Nanovoltmeter
- 3) The optional Keithley Model 2187-4 Test Lead Kit for 2182A simplifies connections to multiple types of devices.

## Alternative Solutions

Other sources with pulsing capability are available on the market. However, none of these solutions provide line synchronization or use the three-point delta method needed to yield accurate measurements when the sourced or measured signals are small. Additionally, most are voltage pulsers, so they can't offer four-wire connections to the device under test without requiring an independent measurement of the device voltage generally. Homemade current sources are not as accurate and cannot source precision current pulses. They also have no programmable compliance, which is a voltage limit that the current source is programmed never to exceed.

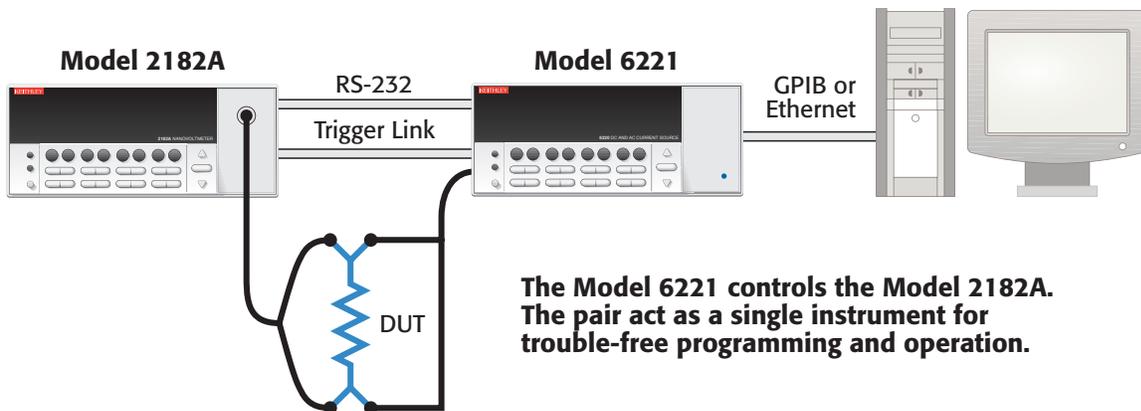


Figure 6: A block diagram of a low-level pulsed test setup using the 6221/2182A combination.

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