KEITHLEY

Application Note Series

Number 2611

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 16μs after the pulse is applied. (See ***Figure** 7*.) The entire pulse, including a complete nanovolt measurement, can be as short as 50μs.

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

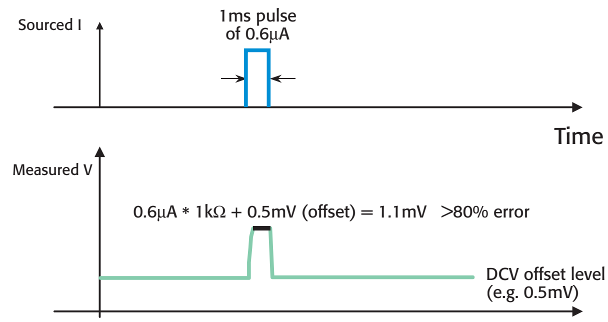


Figure 1a: DC offsets due to thermal voltages and meter offsets can give significant errors in the measured voltage.

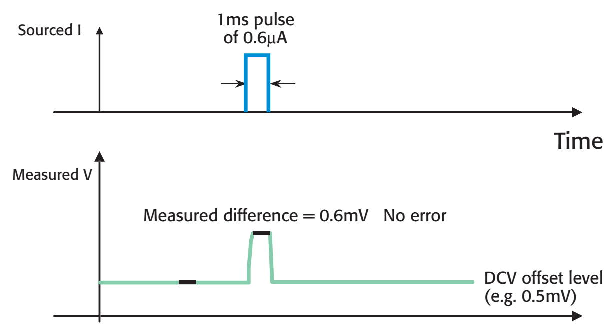


Figure 1b: Performing relative measurements cancels offset error. The measured delta voltage gives correct voltage response to the current pulse.

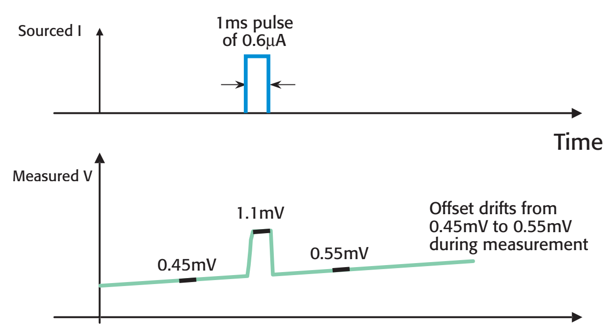


Figure 1c: An optional third measurement point can help cancel moving offsets.

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***.)

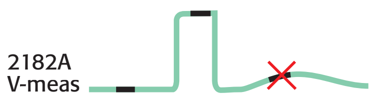


Figure 2. Heat generated by the pulse in the DUT or contacts may corrupt the third measured point, so it may be discarded.

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.

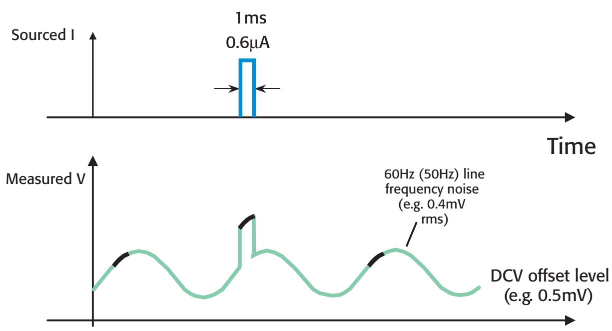


Figure 3: Operating at low voltage levels, measurements are susceptible to line frequency interference. Using line synchronization eliminates line frequency noise.

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.

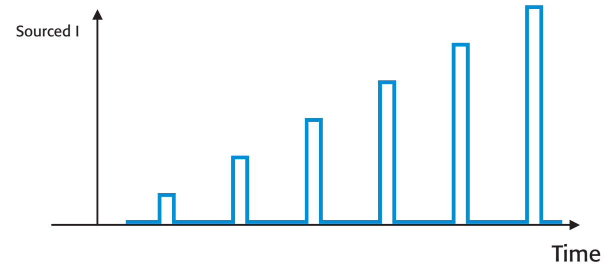


Figure 4: A series of pulses increasing in amplitude.

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.

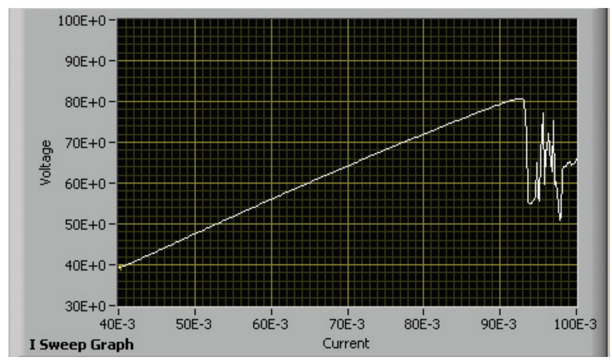


Figure 5a: DC I-V curve from 40mA to 100mA. Testing destroys the DUT.

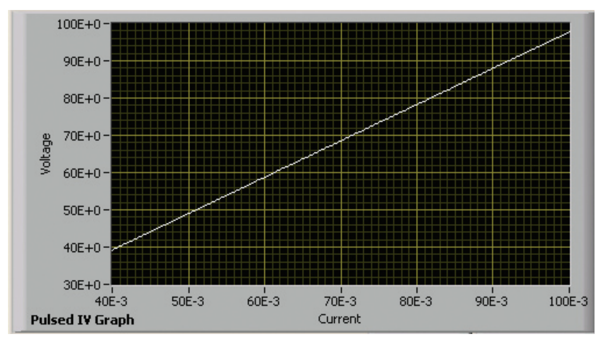


Figure 5b: Pulsed I-V curve over the same range.

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.

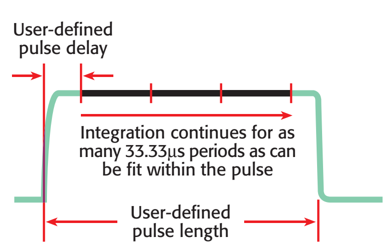


Figure 6. Measurement integration time is automatically maximized.

Test System and Configuration

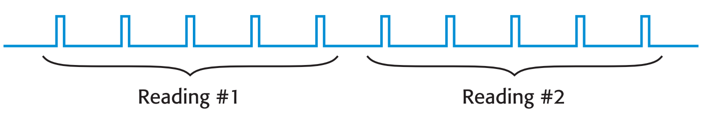
These are some commands to set the Model 6221/2182A up for pulse testing:

Repetitive pulsed test

In this example, we want to do a repetitive pulsed test, pulsing 10mA, with a pulse width of 100μs, repeating ten times per second. Assume that to accommodate device settling time, we want to wait 60μs after the beginning of the pulse before we make the voltage measurement. If the device is a 0.5Ω 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	100μs pulse width	In seconds over bus, in ms via front panel
pdel:sdel 6e-5	CONF→PULSE→SRC-DEL 0.06ms	60μs 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× 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 Command varies with program language		Must read enough bytes from GPIB or Ethernet port: 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.

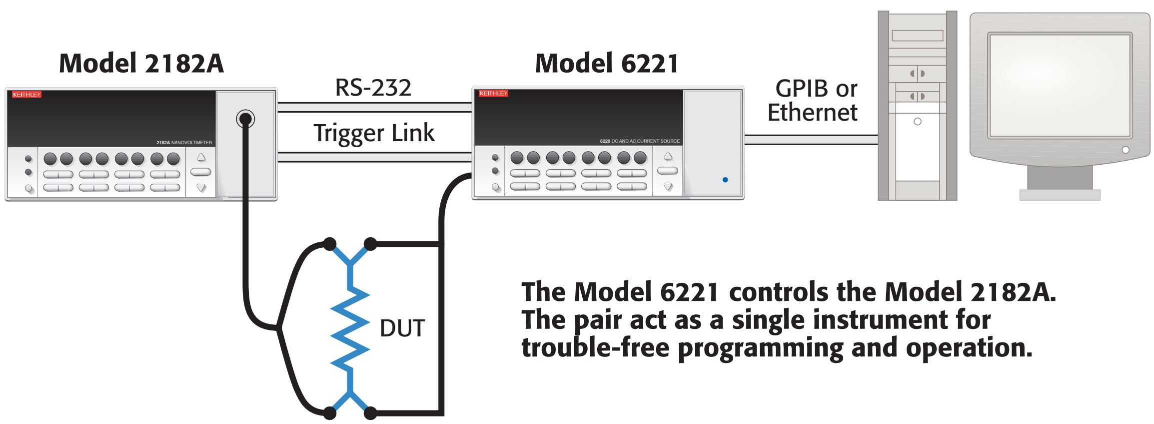


Figure 6: A block diagram of a low-level pulsed test setup using the 6221/2182A combination.

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