Making High Resistance Measurements of Sensitive Devices Using the Keithley 2470 SourceMeter® Source Measure Unit

APPLICATION NOTE

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Introduction

Electrical resistance is a device property that qualifies devices for various applications. Resistance is measured using a variety of instruments like a digital multimeter (DMM), insulation resistance tester, source measure unit (SMU), or an electrometer. Typically, the resistance can be measured by two different techniques with the above-mentioned instruments, i.e., by sourcing current or by sourcing voltage [1]. A DMM instrument, which typically sources a constant current, is good for resistance measurements up to 100 MΩ, or even as high as 1 GΩ with a high precision DMM. For high resistance measurements using current sourcing, the instrument's input impedance is in parallel with device resistance, making high resistance measurements challenging.

For high resistance measurements (typically >1 GΩ), a constant voltage sourcing method is preferred, as voltage can be accurately applied to such devices. This technique is used in many dedicated high resistance measurement instruments like high-R meters, electrometers, and the source measure unit (SMU) for the measurement of resistance values up to 10^{16} Ω and above [2]. The higher the resistance of the device, the larger is the testing voltage required.

Generally, high resistance samples like rubber, paper, textile or even semiconductor devices, are tested at higher voltages >700 V. During such testing, due to dielectric breakdown, if high currents flow, then the device is damaged. So, it is very important to select a proper voltage source considering the current requirements. In other applications such as charging of materials or semiconductor devices, transient high currents damage the device under test (DUT), where different charge states of the material also contribute to the problem. Thus, getting exact repeatable values of the higher resistance sample is very difficult.

Keithley's instruments are time tested and proven in the materials research domain for high resistance and ultra-low current measurements applications. The Keithley 6517B Electrometer is a very popular model for high resistance measurement up to 10^{17} Ω. Keithley also offers other instruments like the 6430 and 2470 SMUs and the 6487 Picoammeter for high R applications.

Test considerations for higher resistance samples

1. The high resistance of a material is a function of many parameters like test voltage, measurement time, device charge state, environment parameters like temperature and humidity, etc. To get accurate high R measurements, it is important to consider a few points.

2. Low current measurement: High resistance measurements are performed by measuring low current from the DUT at a constant voltage. The accuracy of the high resistance measurement is solely limited by accuracy of the current measurement set up. For a device having a resistance of 1 GΩ and above, device current is typically in the order of nAs and below. To accurately measure nA current (and below current), the instrument should have a TRIAX connection with built-in guard. This reduces leakage current in an instrument as well as in the cable assembly. With guarded measurements, currents at 1 fA and lower can be measured [1].

3. Voltage source: The voltage source required for high R measurements should be capable of sourcing more than 700 V; preferably 1000 V (considering a rubber leakage testing application). The voltage source used in such testing should have lower current sourcing capability. During testing, if the device fails, i.e. device shorts, maximum current flows through the device and may damage the device. The voltage source should have a capability to stop sourcing voltage (and current) during "device short" event. If the DUT is a charge sensitive device, then voltage source should have a current limit or current compliance feature, which controls the flow of current from voltage source under all conditions. This is a very critical feature and very few high voltage instruments offer this feature.

4. Measurement Time: High resistance measurements are a function of measurement time. High resistance devices can usually exhibit a high RC time constant. When sourcing to the DUT, the applied voltage will not be sensed by devices at an instant. Thus, it is required

to add some delay, and this needs to be optimize for every device test condition. **Figure 1** shows a time scale measurement sequence for this case:

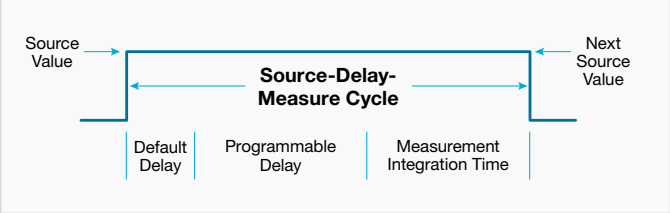

Figure 1: Source-delay-measure cycle for high resistance measurement.

For getting repeatable measurements, it is very important to carry out testing at a fixed delay for all samples.

- Safety features:

As per international safety standards for high voltage sourcing, an instrument having voltage sourcing capability of more than 42 V should have a safety interlock. At such high voltages, all provided cables should have insulator enclosures over all-metal clips. This removes the chances of human contact to any high voltage carrying conductors.

Considering the measurement technique and important basic parameters discussed so far, the Keithley 2470 SMU is a good instrument to measure high resistance. This instrument has a built-in 1100 V voltage source with a current compliance feature. Further, the TRIAX connectors assists for the low current measurements, especially when using the 10 nA current range (having accuracy of 0.1% of reading +250 pA) [3]. The user also can add programable delay during testing. Additionally, the 2470 includes a built-in interlock feature for user safety. Without the interlock properly engaged, the 2470 will never output more than 42 V, protecting the user. All provided cables are covered with high-quality rubber encapsulation on metal clips.

The 2470 SMU has an advantage over some electrometers and other high resistance measurement instruments. While most electrometers and high resistance meters have 1000 V voltage sources, they do not have the ability to set a source limit, which is sometimes referred to as a Compliance Limit. Source Limit or current compliance prevents the instrument from sourcing a current over a set value when outputting a voltage. This helps to prevent damage to the DUT. While you can achieve something similar with an electrometer by selecting different current measurement ranges, it doesn't help much when measuring and protecting sensitive devices. Full scale of the electrometer current measuring range becomes the compliant limit, which may damage the DUT due to a higher compliant limit.

Device Connection

The 2470 has a touchscreen front panel, reducing the learning curve and dramatically improving the user experience. The connection for any device should be done using rear panel triax connectors. The high resistance device should be connected between 'Force HI' and 'Force Lo' connectors as shown in **Figure 2**.

Figure 2: The 2470 SMU rear panel connection and front panel view.

Configuring the test

Front panel set up

After the device is connected to the TRIAX connectors on the rear panel of the 2470 as shown in **Figure 2**, the instrument needs to be configured for measurement. For this, the following steps need to be followed for the measurement of device high resistance.

1. On the 2470 front panel, press the front/rear input selector button to connect the instrument to rear connection. Please make sure “R” is displayed near this button.

2. Press the **FUNCTION** key and select **Source Voltage and Measure Resistance** (as shown in **Figure 3**). Choose the desired source voltage (e.g. 500 V) and a current source compliance value by using the front panel touchscreen buttons. Based on the test voltage and the expected value of the resistance to be measured, calculate the expected current value (I=V/R) and set the source limit high enough that it will not impede the current flow. For example, if the expected resistance is 1 GΩ and the test voltage is 500 V, then the expected current is 500 nA. An acceptable setting for the source limit in this case would be 1 µA.

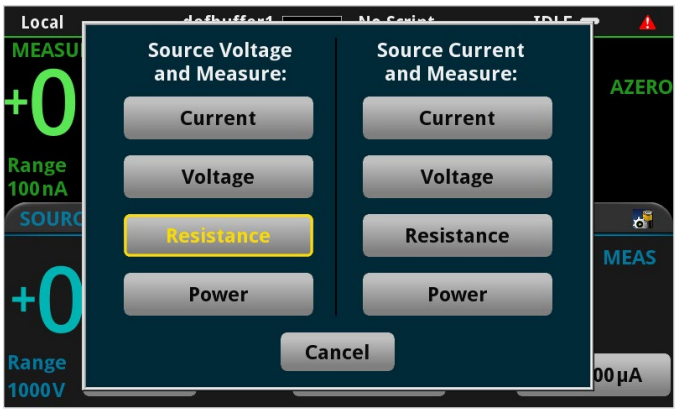

Figure 3: Menu to select Source Voltage and Measure Current.

3. Press **MENU**. Select the **Templates** option under Trigger. In the TRIGGER MODEL TEMPLATES window, hit the button to bring up the various template options. Select the **SimpleLoop** trigger model. In this trigger option, set the count to 100 and delay to 100.00 s. Please refer to **Figure 4** for more details.

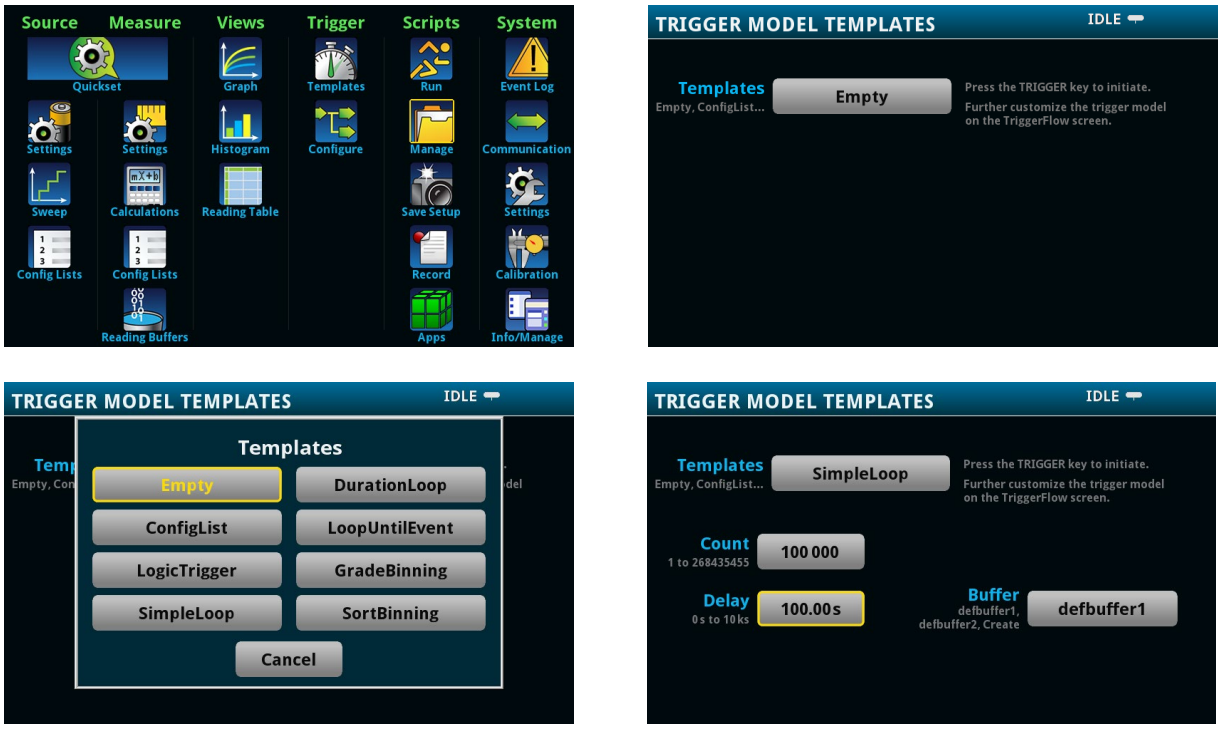

Figure 4: Menu to select the Trigger Model Templates.

4. Press the **HOME** button on the front panel to return to the main display. Press **Output On/Off** to turn the output on, then press the **TRIGGER** button on the front panel. This will start the measurement and automatically switch off the source after the measurement is completed.

5. For every repetitive measurement, after connecting a new DUT, the user only needs to press the **TRIGGER** button to restart the measurement process.

Notice the measured resistance is displayed in the top half of the touchscreen as shown in **Figure 5**.

Figure 5: Tera ohm resistance measured using the 2470 SMU.

All of these measurement steps can be automated by a simple script and executed in the 2470. A sample script for this kind of application is given in Appendix A.

Steps to Generate, Download, and Execute a Script

Here are the simple steps to create and execute a script on the 2470:

1. By using Keithley's Test Script Builder (TSB) Software or some other tool like Notepad, create a script to perform a high R measurement using the TSP™ command set. TSB is a software tool available for the 2470 that will enable you to execute the script before you download it to the unit. For your convenience, you can copy the script listed in this application note and modify it.

2. Save the script as a .tsp file on a USB drive, and insert the USB drive into the 2470's front panel USB port.

3. Once the USB drive is inserted, all .tsp files on it will appear in the MANAGE SCRIPTS window. This can be accessed by pressing the MENU key and then Manage Scripts. Copy the script to 2470 by clicking on the arrow button.

4. To Run the test, please touch "No script" on front panel and select the script (e.g. *Sensitivedevicetesting*) as shown.

Figure 6: Running test script for Automatic testing.

5. This automatic test will ask for queries/inputs like "Do you want to Run the test", inputs for voltage, delay and current limit. Once the user provide all inputs, the test will be run, and source voltage will be OFF after each test.

6. Then it will ask the user "Are you ready to test the DUT?". If the user provides an input as "YES", the automatic script will repeat the measurement and store the readings for all tested devices in the buffer. If the user selects "No", the script will be terminated.

7. The user can save the data from Buffer to USB.

8. In this test, if the device attempts to draw current >1 µA (with 1 µA current compliance), the 2470 will not apply the set voltage (500 V) to the DUT. The SMU will automatically reduce the voltage to keep the current to less than 1 µA. The displayed voltage measurement will change to Yellow along with the "Limit" label and the "LIMIT" indicator if the current limit is in effect. This makes device testing very safe by preventing excess current from flowing through the device.

Safety Considerations

When testing at high voltage, safety is of utmost concern. The 2470 SMU can generate voltages up to 1.1 kV. Precautions must be taken to ensure that the operator is not exposed to unsafe voltage:

- Enclose the device under test (DUT) and any exposed connections in a properly grounded fixture such as the Keithley 8010 test fixture as shown in **Figure 7**.

Figure 7: Properly grounded testing fixture.

- Use the safety interlock provided on the rear panel of the 2470 SMU as shown in **Figure 8**. The 2470 is fully interlocked so that the high voltage output is turned off if the interlock is not engaged. The interlock circuit of the SMU should be connected to a normally-open switch that closes only when the user access point in the system is closed to ensure that operators cannot meet a high voltage connection to the DUT. For example, opening the lid of the test fixture should open the switch/relay that disengages the interlock of the 2470 SMU.

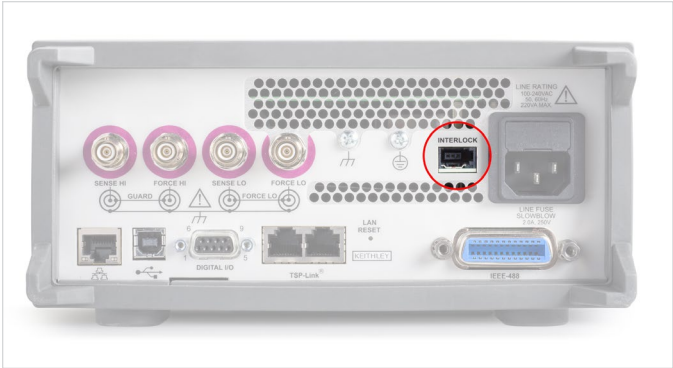

Figure 8: Location of safety interlock connection on rear panel of 2470 SMU.

- Use cables and connectors rated to the maximum voltage in the system. Keithley's TRX-1100V-* high voltage triax cables are designed for the 2470 and meet today's high voltage safety standards.
- Always use the proper safety gloves when working with high voltages on energized components as shown in **Figure 9**.

Figure 9: Using proper safety gloves when working with high voltages on energized components.

Conclusion

The Keithley 2470 SourceMeter SMU Instrument is an ideal tool for device resistance testing of charge sensitive devices or for measuring the high resistances of other materials/ device. This SMU can source voltage and measure resistance with source current limiting. The 2470 enables the user to specify the test voltage, measure the resistance with a user-defined delay and a source current limit, and shows the results on the display of the instrument. This qualifies the Keithley 2470 SMU as a high resistance measuring instrument.

Reference

1. Low level measurement hand book, https://in.tek.com/document/handbook/low-level-measurements-handbook
2. Keithley 6517B electrometer datasheet, https://in.tek.com/search?keywords=6517B&facets=_templatename%3dDatasheet&sort=
3. Keithley SMU 2470 data sheet, https://in.tek.com/search?keywords=2470&facets=_templatename%3dDatasheet&sort=

About the Author

Dr.Abhaykumar Joshi has completed his M.Sc.(Electronic science) and Ph.D (Electronic Science) from University Of Pune. During his research, he worked on thin films, sensors, MEMS, piezoelectric materials and simulation. Since 2011, he is working with Keithley-Tektronix India as an application engineer and business development manager.

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Appendix A: Application Script

```
-- Reset the instrument
reset()
--User input voltage
tv = display.input.number("test voltage in V", display.NFORMAT_PREFIX, 500, -1000, 1000)

--User input delay
d = display.input.number("test delay in sec", display.NFORMAT_PREFIX, 10, 0, 100)

--User current limit
curr = display.input.number("current limit in test (uA)", display.NFORMAT_PREFIX, 1, 0, 10000)
curr =curr *1e-6
-- Set up the source function.
smu.source.func = smu.FUNC_DC_VOLTAGE
smu.source.ilimit.level = curr
smu.source.level = tv
-- Set up the measure function
smu.measure.func = smu.FUNC_DC_CURRENT
smu.measure.unit = smu.UNIT_OHM
smu.measure.terminals = smu.TERMINALS_REAR
smu.measure.autorange = smu.ON
smu.measure.nplc = 10

-- Turn on the source output and take readings.
for i=1, 501 do
SaveChoice = display.input.prompt(display.BUTTONS_YESNO, "are you ready to test the DUT?")
if (SaveChoice == display.BUTTON_NO) then
break
end
if (SaveChoice == display.BUTTON_YES) then
smu.source.output = smu.ON
delay (d)
smu.measure.read(defbuffer1)
smu.source.output = smu.OFF
end
end
```

Appendix B: Recommended Components For This Application

- Qty 1: 2470 SourceMeter
- Qty 1: Safety test fixture (Keithley 8010 suggested)
- Qty 2: TRX-1100V-2 cables
- Qty 1: Safety interlock cable (review 2470 users manual for details)

The 2470 Users Manual can be downloaded at: https://download.tek.com//2470-901-01B_Sept_2019_Ref.pdf

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