KEITHLEY
A Tektronix Company

Application Note Series

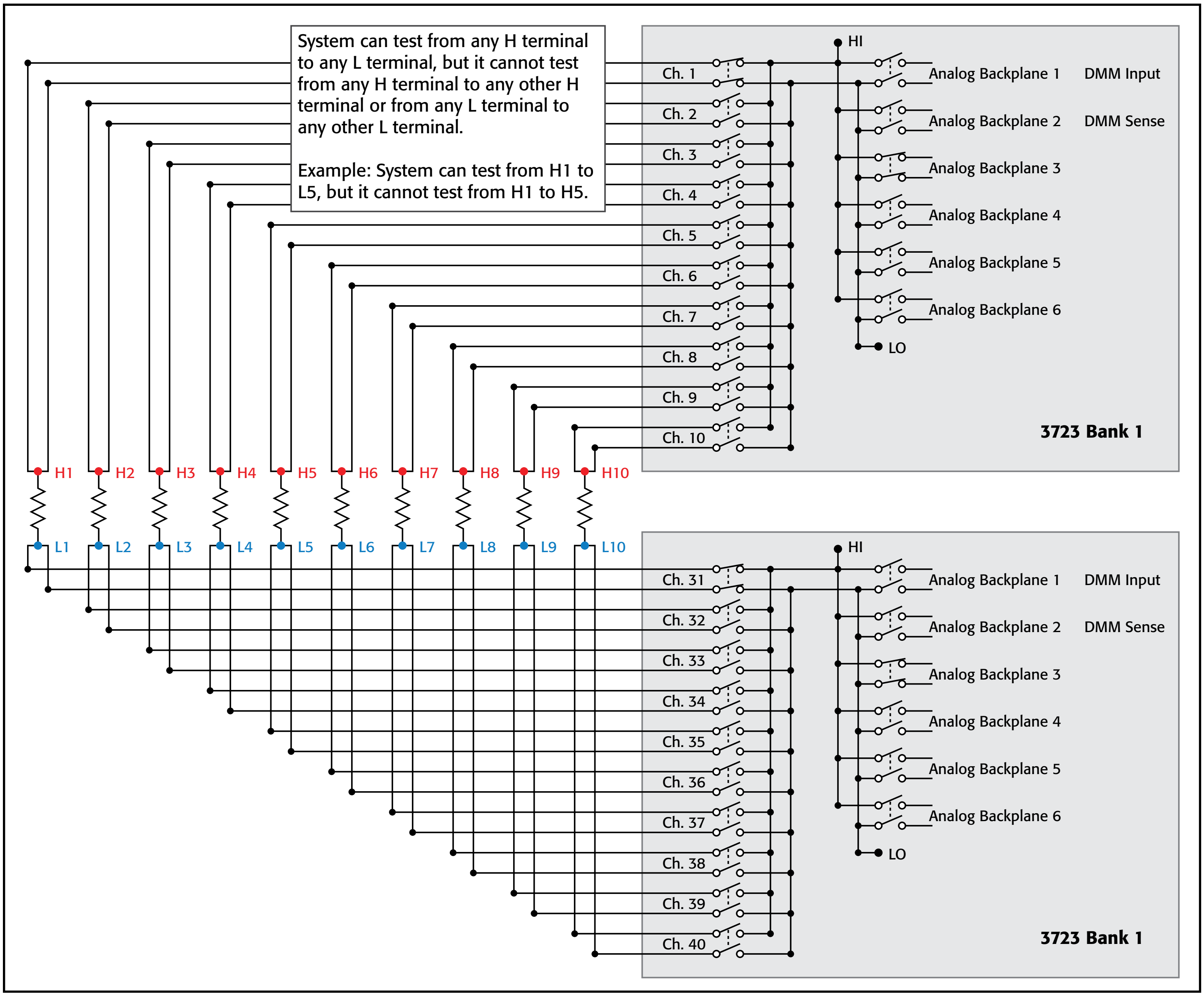
Number 3080

LLCR Pin Socket Testing with the Model 3732 High Density Matrix Card

Introduction

Computer processors (CPUs) today have come a long way from the computer processors of the past. They draw more power, run at lower voltages, and have more pins than ever before. Meanwhile, they can still be dropped into a CPU socket without the need to be soldered. With such large current draws, any significant resistance in the contacts between the CPU and the socket can cause large voltage drops and excess heat, rendering the CPU inoperable. Because of this, it is critical that the contact resistance be minimized. To ensure this requirement, thorough testing of sockets must be performed. This testing usually comes in the form of Low Level Contact Resistance (LLCR) testing.

In an LLCR test, the resistance of a set of contacts is measured using low level signals. The test is performed by sourcing current in the 1nA to 100mA range across the contacts being evaluated and measuring the resultant voltage drop. Due to the small resistance values found on the contacts, this voltage drop is



System can test from any H terminal to any L terminal, but it cannot test from any H terminal to any other H terminal or from any L terminal to any other L terminal.

Example: System can test from H1 to L5, but it cannot test from H1 to H5.

Figure 1. Four-wire cable test connections using a multiplexer

typically very small (in the microvolt range) and thus requires a high quality voltmeter to obtain accurate readings.

LLCR tests are performed on CPU sockets by placing an interposer over the socket and then measuring the resistance between various sets of pins in the socket. The interposer creates a path across a number of contacts, and thus the measured resistance is the sum of the contact resistances of the individual pins. The total contact resistance is then divided by the number of contacts in the path to get the average contact resistance. Typical desired contact resistance is under 17-20mΩ per contact.

Test System Design

Due to the variety of socket sizes and layouts and the different interposers that can exist for a single socket, it is desirable to have a test system that can adapt to new probe patterns without requiring manual rewiring of the test system. The test system should be flexible enough to adapt to a new layout simply with programming and should provide the ability to test from any pin in the socket to any other pin in the socket. Also, due to the low resistances involved, the system must use Kelvin connections.

SMU Solution

One way to implement this kind of system is to use several source measure units (SMUs), with one SMU per pin, and perform your tests from one SMU to another. However, at hundreds or thousands of pins per socket, this is neither cost nor space effective. A much cheaper and more efficient solution would be to combine switching hardware with a single set of measurement instrumentation and allow the switch to connect the instruments between the socket pins.

Multiplexer Solution

Most test systems requiring switching can be built using multiplexer cards. With multiplexers such as Keithley's Model 3722 Dual 1×48 High Density, Multiplexer Card and some simple wiring of the Model 3706A switch mainframe's analog backplanes, very dense cable test systems can be created. These systems allow full 4-wire Kelvin testing from any pin at one end of the cable to any pin at the other end of the cable. It does this by connecting the two banks of the multiplexer to the two ends of the cable then re-wiring the backplane to route Bank 1 signals to the Digital Multimeter's (DMM's) HI and Sense HI inputs and Bank 2 signals to the DMM's LO and Sense LO inputs. An example of this system can be seen in ***Figures 1*** and ***2***.

In essence, this sounds very similar to the procedure for the socket pin test. However, this system has a limitation that makes it unsuitable for this particular application; it cannot test between pins that are on the same side of the cable. For example, for a test between pins H1 and H5, ***Figure 1*** shows that it is not possible to route both the DMM HI signals and DMM LO signals to the pins at the same time. In a socket test system where a test needs to be done between any two pins in the system, this setup is insufficient.

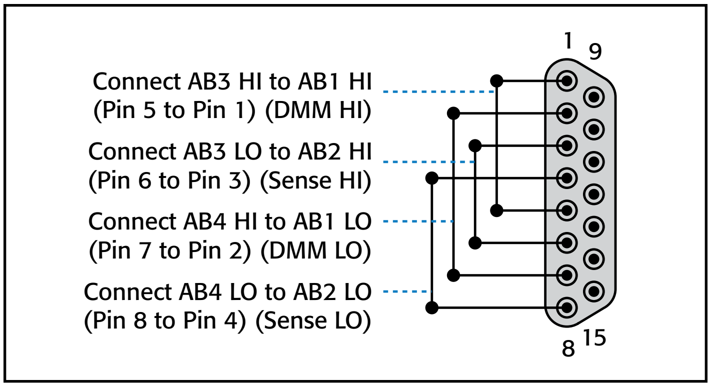


Figure 2. Backplane connections for 4-wire cable test using a multiplexer

In order to get any pin to any pin switch capability from multiplexers, one multiplexer is needed for each pin in the system, and each multiplexer must have as many channels as there are pins in the test system (minus the one for itself). For example, to test a 40-pin socket, 40 1×40 differential multiplexers are necessary in order to perform 4-wire Kelvin measurements from any pin to any pin. This would correspond to 40 Model 3721 Dual 1×20 Multiplexer cards and would require seven Model 3706A mainframes to house them. This is by no means practical.

Matrix Solution

LLCR pin socket testing requires a switch card with maximum flexibility. No card provides this as simply and easily as a switch matrix card. Because of this, choose the Keithley Model 3732 Quad 4×28 Single Pole, Ultra-High Density, Matrix Card. Its four rows provide the exact number of lines required for 4-wire Kelvin connections and the single-pole crosspoints offer the ability to route each signal to exactly where the user desires.

The Model 3732 matrix card has density. In the previous example using multiplexers, it would require 40 Model 3721 cards and 7 mainframes to house a 40-pin test system that has the required flexibility needed for our test system. With the Model 3732 configured as a 4×112 matrix, only one Model 3706A mainframe and a single Model 3732 card are required to create the same system. Using the Model 3732 there can be a total of 56 test pins per card (two columns per pin: one source, one sense) for a total of 336 four-wire Kelvin pins per mainframe. (A mainframe can contain up to six Model 3732 cards.) In addition, thanks to the analog backplanes of the Model 3706A, the number of columns across multiple cards (as well as connected to the internal DMM) can be further expanded without any external wiring. If a single mainframe is not large enough, the columns across mainframes can also be expanded with only four wires by connecting the Model 3706A analog backplanes together. This results in high density systems; for example, 1000-pin tests can be performed with less than four full mainframes.

Current Source and DMM Selection

To achieve the desired density in the system, select the Keithley Model 3732 Ultra-High Density Reed Relay Matrix Card and the Keithley Model 3706A System Switch/Multimeter; however, test signals are still needed. Within the Model 3706A is a precision 7½-digit DMM capable of making 4-wire Kelvin resistance measurements. With $1\mu\Omega$ resolution, the DMM in the Model 3706A is completely capable of making the low milli-ohm measurements required for LLCR testing. However, the problem with any DMM is that the current they source to perform measurements is a fixed value. In a low level contact resistance test, the current required varies depending on the device under test (DUT). To have a truly flexible system it is much better to use a precision current source to source the exact amount of current needed. Then, use the voltmeter on the internal DMM to measure the voltage and calculate the resistance.

While any precision current source would work for this application, a Keithley Model 2612B SourceMeter® instrument will maximize speed and simplicity. The Model 2612B precisely sources and measures the current levels of this application and integrates with the Model 3706A using Keithley's TSP-Link® technology. This combination of hardware provides the framework for an incredibly fast and accurate test system. Using TSP-Link and the embedded Test Script Processor (TSP®), both the Model 2612B and the Model 3706A Switch/DMM can be controlled from a single script. Switch, source, and measure operations between the instruments can be synchronized without the use of external digital I/O. Also, thanks to TSP-Link and the advanced trigger models of both instruments, the required tests can be performed at maximum speed through the use of scans and sweeps.

If the Model 2612B can perform 4-wire Kelvin resistance measurements, why is the DMM in the Model 3706A necessary? If the DUT resistances in this application were higher, then the DMM would probably not be necessary because the voltage levels would be higher. The DMM is necessary, however, because it has a higher resolution voltmeter than the Model 2612B (7½ digits vs. 5½). At these low levels, the voltmeter of the Model 2612B does not have enough resolution to achieve the desired accuracy, the 3706A's DMM is used to measure the voltage across the DUT.

Application Details

This test system is both flexible and scalable because of the architecture of the Model 3732 ultra-high density matrix card. Being a single-pole matrix, this card has the ability to route any signal to any pin. This same architecture also allows the system to expand, often without external wiring, simply by closing relays on the analog backplane.

In a typical socket test, for any particular part being tested, the pins to be tested between are usually predetermined. The Model 3706A tailors to this through the use of switch patterns. A pattern allows you to take multiple channels and group them together such that an open or close of that pattern will open and close those channels all at the same time. For a particular test, the user would simply hard code in a predetermined set of switch patterns then add these patterns to a scan to perform the test. In a typical test, these patterns do not include every pin in the socket. In order to demonstrate the power and flexibility of this test system, the following explains how to test every pin to every other pin in the system.

Required Equipment

In this example, assume that the DUT has 56 pins to test. To complete tests on this DUT the following equipment is needed:

- One Model 3706A System Switch/Multimeter
- One Model 3732 Ultra-High Density, Matrix Card
- One Model 3732-ST-C Column Expansion Screw Terminal
- One Model 2612B System SourceMeter Instrument
- One Model 3706-BKPL Backplane Connector
- One Model TSP-Link Crossover Cable
- One PC with Interface for Instrument Control

System Connections & Configuration

Communications

Before any testing can be done, everything must first be connected. Communications simply require a TSP-Link cable between the Model 2612B and the Model 3706A, and a GPIB or Ethernet cable between the Model 2612B and the computer (see ***Figure 3***). No additional wires are needed for triggering as these lines are built into TSP-Link.

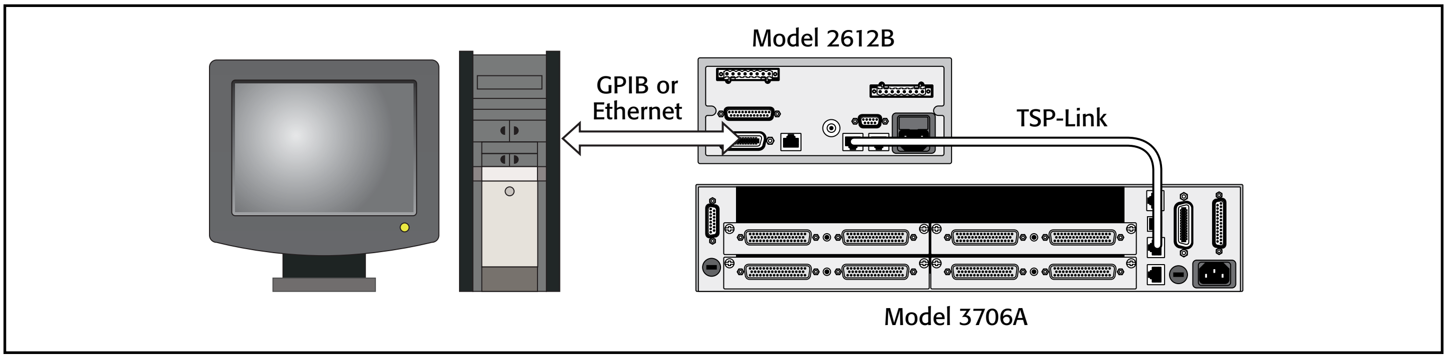


Figure 3. System communications hookup

This system takes advantage of TSP-Link technology so the instruments must be setup properly to use it. For this setup the Model 2612B is configured as the master node, while the Model 3706A acts as a slave. Configure the 2612B as TSP-Link node 1 and the 3706A as TSP-Link node 2. This can be done from the front panel of each instrument by pressing the MENU button then selecting TSPLINK from the Main menu. From the TSPLINK menu select NODE and then configure the node number. Press ENTER to accept the changes.

Matrix Configuration

Next, the Model 3732 Ultra-High Density Reed Relay Matrix Card must be configured. This is done by setting a pair of jumpers on the Model 3732-ST-C screw terminal block. Set the jumpers for the 4×112 configuration (see ***Figure 4***).

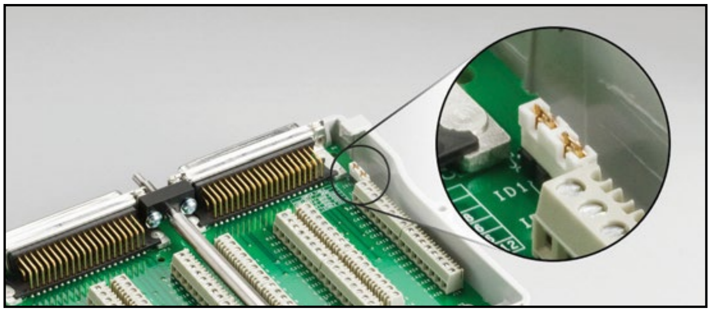


Figure 4. Model 3732-ST-C jumper settings for 4×112 configuration

Test Signals

Finally, the test signal connections must be hooked up. Thanks to the flexibility of the Model 3732, this is easy. The only wiring required is from the Model 3732 to the probe pins and from the Model 2612B to the Model 3706A. The probe pins connect to columns of the Model 3732 card. Adjacent columns on the card will be used to test a single socket pin, with one column being used for the source lead and the other column used for the sense lead. The Model 2612B connects to the Model 3706A through the analog backplane connector, which allows the Model 2612B to connect to the Model 3732 regardless of in which slot it is located. This also supports easy expansion of the system to multiple cards.

The Model 3732 Ultra-High Density Reed Relay Matrix Card is designed so that the rows of the card can be connected to the analog backplane of the Model 3706A mainframe. This allows column expansion without the use of external wiring as well as the ability to connect to the Model 3706A's internal DMM. In the Model 3732, each row of the matrix maps to an analog backplane line. The mappings for the 4×112 configuration used in this application can be seen in ***Table 1***.

Table 1. Backplane to row mappings for 4×112 configuration

Row	Analog Backplane
1	A1 HI, A3 HI, A5 HI
2	A1 LO, A3 LO, A5 LO
3	A2 HI, A4 HI, A6 HI
4	A2 LO, A4 LO, A6 LO

Because the HI and LO signals of the Model 3706A's internal DMM are tied to analog backplane 1, Rows 1 and 2 of the matrix will be used to connect to the DMM by default. This leaves Rows 3 and 4 to be used for the HI and LO signals of the Model 2612B. To facilitate system scalability, rather than connect the Model 2612B directly to Rows 3 and 4 of the Model 3732 card, the Model 2612B will be connected to an analog backplane of the Model 3706A instead. The table shows that the Model 2612B can be connected to analog backplane 2, 4, or 6 as these are tied to Rows 3 and 4. Knowing that the 4-wire sense lines of the Model 3706A's internal DMM are tied to analog backplane 2, connect the Model 2612B to analog backplane 4 or 6 to ensure that the Model 3706A's DMM will not cause interference or load the circuit in any way. In this example we are using analog backplane 4. See ***Figure 5*** for details.

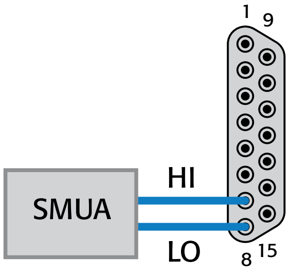


Figure 5. Connect the Model 2612B SourceMeter instrument to analog backplane 4 through the analog backplane D-Sub connector

With the test instruments connected to the rows, the test pins will be connected to the columns. Each test pin has a Kelvin connection, therefore, each test pin requires that two columns be connected to it, one for the source signal and one for the sense. To facilitate simplicity in wiring and channel mappings, adjacent columns should be used to create source-sense pairs for the test pins. For example, columns 1 and 2 should be connected to test pin 1's source and sense leads. Columns 3 and 4 should be connected to test pin 2. This continues for as many test pins as needed in the system.

Figure 6 shows these connections in detail. Note that when scaling this system up, this pattern should be maintained throughout the system, across cards and mainframes.

Test Sequence

Each test on a socket is performed between two test pins. One of these test pins acts as the HI terminal of the DUT while the other acts as the LO. This means we must route the HI source and sense lines of the test instruments to one test pin and the LO source and sense lines to the other. To do this, close four crosspoints as shown in ***Figure 7***.

With this configuration, one pin to all others can be easily tested by simply fixing the HI signal on one pin and scanning the LO signal across all the other pins. Then, move the HI signal to the next pin and repeat the scan of the LO signal across all other pins. This process can be repeated over and over until each pin has been tested against all other pins. See ***Figures 8***, ***9***, and ***10*** for an illustration of this procedure.

The figures show the measurement paths and thus the relays that must close for each step in the test. By examining ***Figures 8***, ***9***, and ***10***, you can see that the required relays to be closed move in a fixed pattern with each step of the test; two columns right per step. This provides a simple pattern in the channel mappings to write code against.

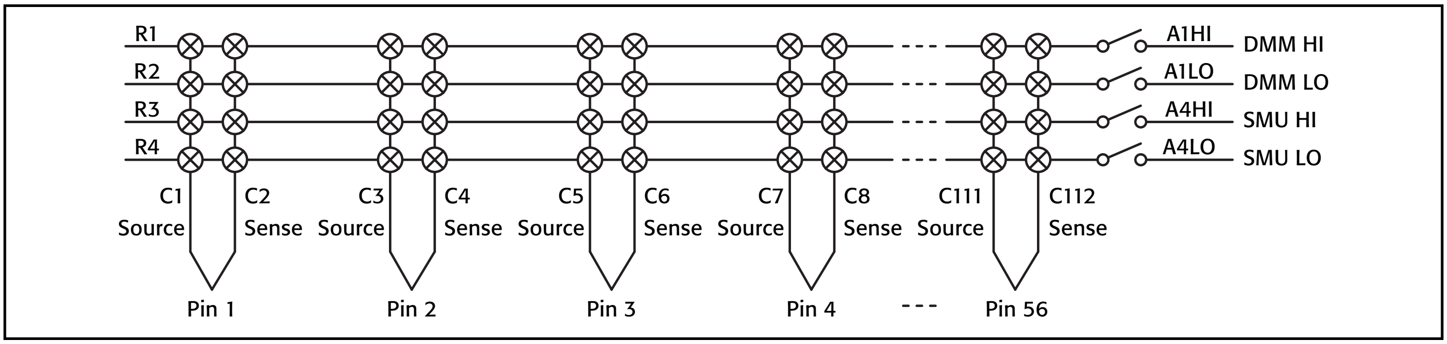


Figure 6. Column to pin mappings

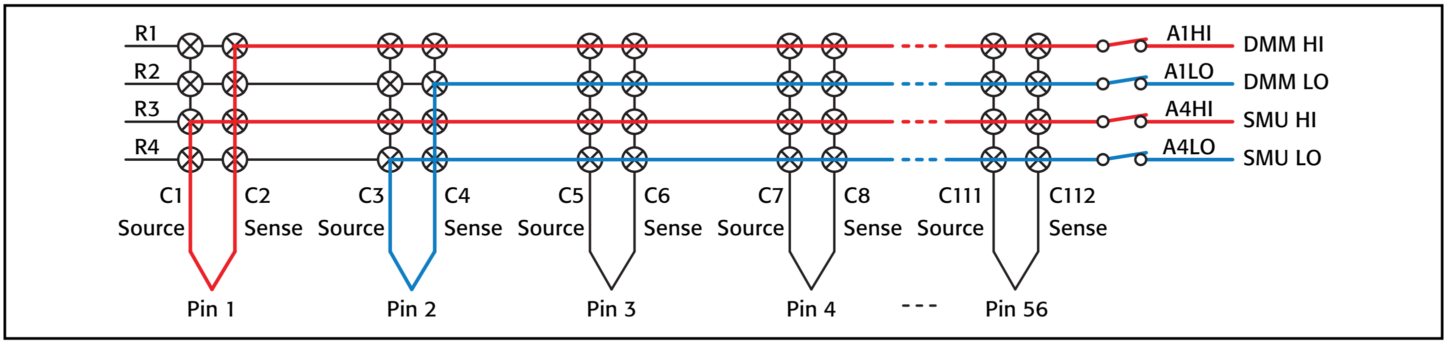


Figure 7. Close these four crosspoints to test from pin 1 to pin 2

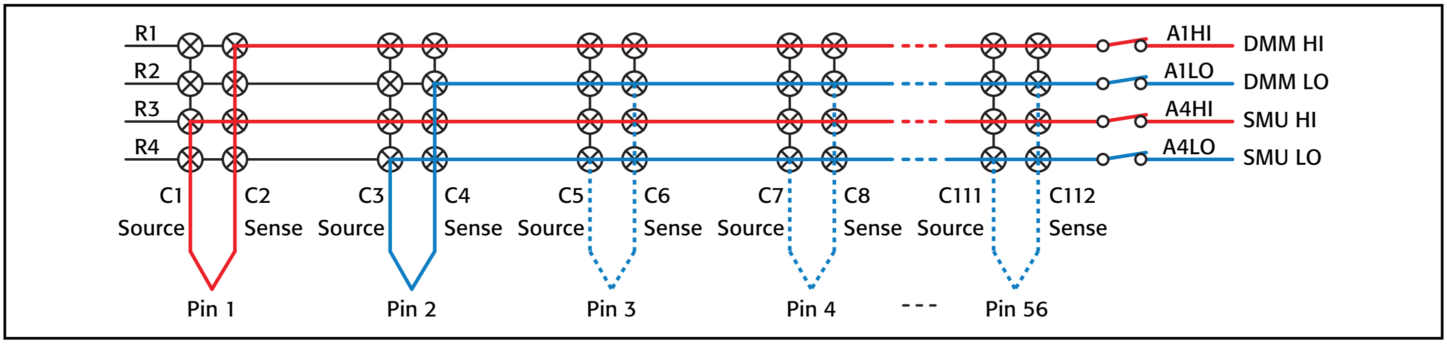


Figure 8. Test from pin 1 to every pin

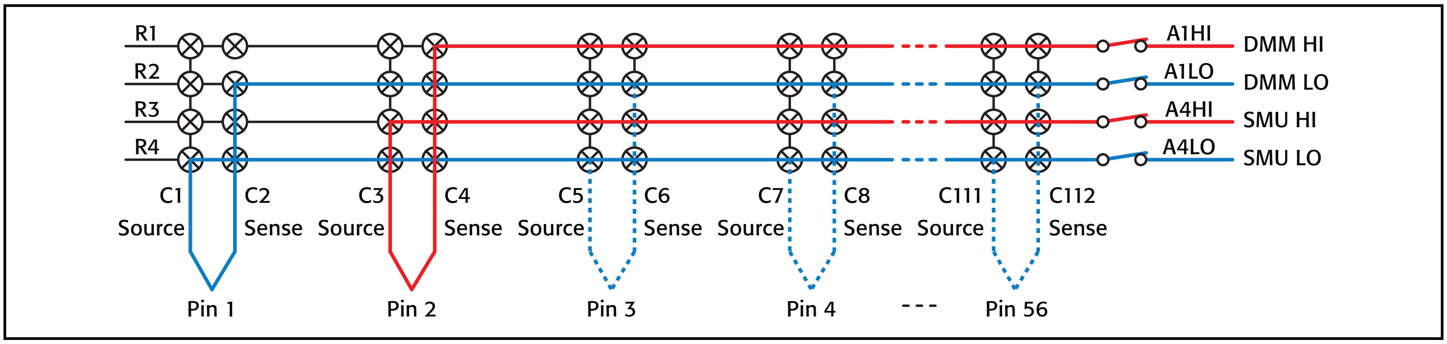


Figure 9. Test from pin 2 to every pin

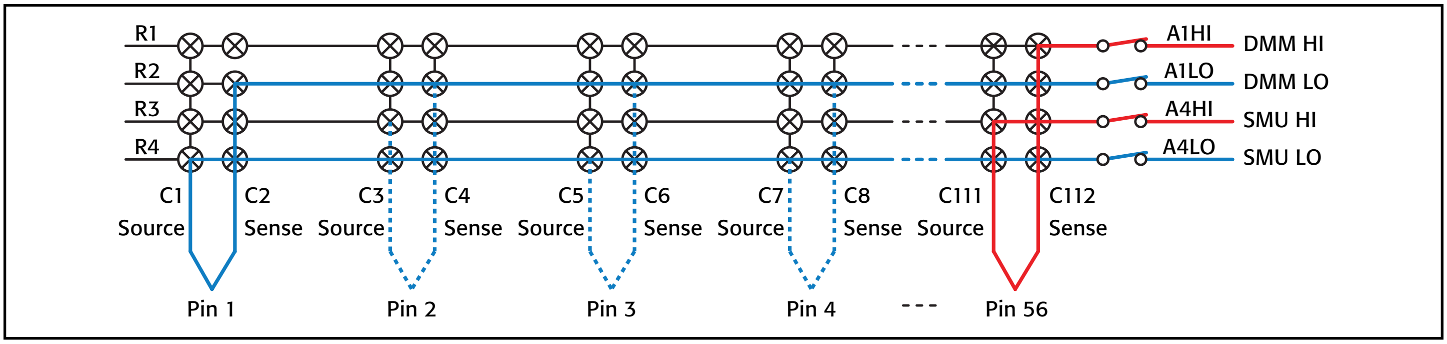


Figure 10. Test from pin 56 to every pin

Trigger Model Setup

The Model 3706A System Switch/Multimeter and the Model 2612B System SourceMeter instrument both include an advanced trigger model for tight timing and synchronization of switch and SMU operations. Using these features, the test can be configured to run as quickly as possible without the worry of operations becoming unsynchronized. The script in Appendix A takes advantage of the trigger model to synchronize the operations between a scan running on the Model 3706A and a sweep running on the Model 2612B. The configuration of the trigger model for this test can be seen in ***Figure 11***. Because the trigger model can be intimidating for newcomers, the script also includes a version of the test written entirely through script operation and makes no use of the trigger model.

By using the trigger model, the overhead associated with processing script commands is eliminated, which can dramatically decrease the time required to test. In this test, 56 pins are tested for a total of 3,136 test points. With all automatic functions turned off and an NPLC setting of 0.1, the test execution time in the script for this test was 18.261 seconds, equating to a scan rate 171.73 channels per second. The test execution time for this same test performed using the trigger model was 9.517 seconds, or 329.52 channels per second; a 91.9% speed increase. At higher NPLC settings, there is less of an improvement as the measurement itself becomes a much greater source of delay than the command processing overhead. The greatest improvement can be achieved at lower NPLC settings.

Running the Test

Testing with this system is performed through the use of test scripts and the Keithley Test Script Builder (TSB) software. However, if an Ethernet interface is being used, then TSB Embedded can be used instead. Source code for this script can be found in Appendix A.

The script in Appendix A is designed for use with a single Model 3732 card placed in slot 1 of the Model 3706A mainframe. It takes advantage of new ICL commands that were introduced with Model 3706A firmware release 1.40 (so firmware version 1.40e or later is required).

For simplicity of test setup, the DUT will be a two-foot length of standard computer ribbon cable rather than an actual pin socket. This provides a low resistance DUT without requiring a pin prober as the cable can easily be wired directly into the Model 3732-ST-C Screw Terminal Block. Based on the column to pin mappings shown in ***Figure 6***, the 4×112 configuration can provide 56 test pins. Each wire in the cable requires two pins to test, one at either end of the wire, thus with a single Model 3732 we can test up to 28 wires in the cable. For this test, one end of the cable will be connected to pins 1 through 28 and the other end to pins 29 through 56. With the DUT wired this way, a clear pattern will appear in the collected data, demonstrating the flexibility the test system provides.

The test script for this system has been designed to be easy to use and requires the user to call only one function in order to run the test. A test can be initiated with a call to: `, measRngV, pins)`. `PinTestScan()` has three parameters for customizing the test.

• `srcLevel`	The current level, in Amps, to source during the test
• `measRngV`	The measure range, in Volts, to be used during the test
• `pins`	The number of pins to test. Can be any value between 1 and 56

To run this test, connect to the Model 2612B in TSB and download the script. In this example, `srcLevel` is set to 5mA, `measRngV` to 100mV, and `pins` to 56. In the Instrument Console window, type `PinTestScript(5e-3, 0.1, 56)` then press Enter. The test will run until every pin has been tested. With these settings, all 56 pins will be tested against all 56 pins for a total of 3,136 test points.

Analyzing the Results

The collected data is formatted so it can be copied directly from the Instrument Console window and pasted into a Microsoft® Excel® spreadsheet. Once pasted, the data will appear in a grid, 56 rows by 56 columns. Each row indicates the position of the HI pin while each column indicates the position of the LO pin. This allows you to easily find the measured resistance value between any two pins. For example, if you wanted to know the resistance

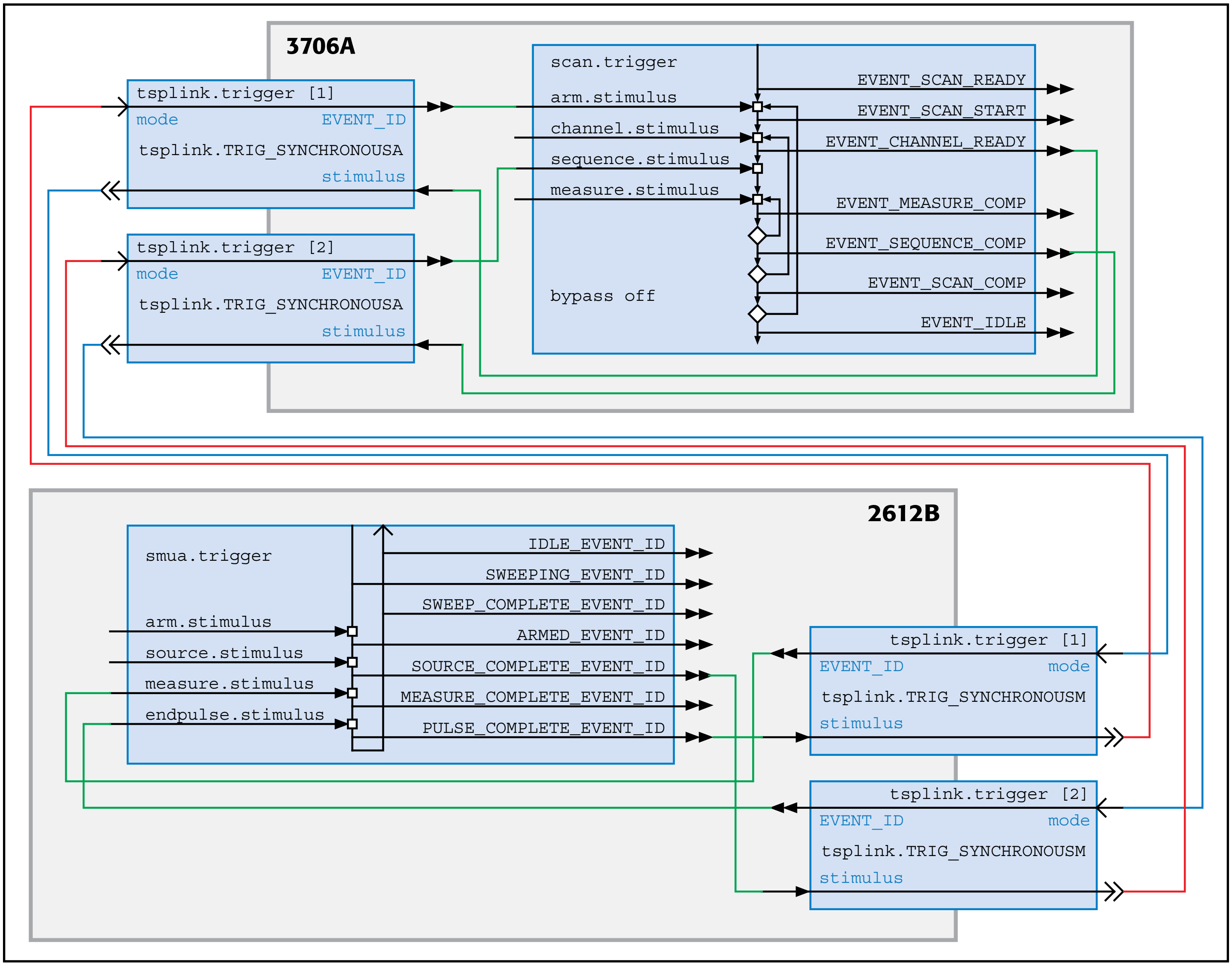


Figure 11. Trigger model for synchronous Model 3706A and Model 2612B operations

of wire 2 in the cable, you know that one end of the wire is at pin 2 while the other end is at pin 30. Simply look at row 2 column 30 to find the measured resistance value.

With the data pasted into Excel, highlight all of it. From the Format menu select Conditional Formatting… The Conditional Formatting window will appear. Add a rule to highlight, in the color of your choice, numbers between –1 and 1. This will cause the data to be highlighted only if the measured resistance value is small. Click OK to accept the formatting. The formatted data collected can be seen in Appendix B.

Notice the pattern that appears in the highlighted data and which rows and columns are highlighted. As can be seen in Appendix B, data is only highlighted under two conditions; when the HI and LO pins are on either end of the same wire in the cable or when they are the same pin.

The highlighted measurements toward the upper right of the spreadsheet are the measurements from one end of the cable to the other. The highlighted measurements at the lower left of the spreadsheet are also from one end of the cable to the other, however, the HI and LO pins are now on opposite ends of the cable. The highlighted measurements down the center are caused by the HI and LO pin being the same pin.

With the measurements in the upper right and the lower left being of the same DUT, just in opposite directions, one would expect the resistance values measured to be closer than they are. This difference in measured value is caused by thermal offsets. Because the voltages being measured are so small, the thermal offsets have significant effect on the measurements. However, since the thermal offsets only act in one direction, we can eliminate these effects and get a true resistance value by taking a measurement in both directions and averaging the two readings. This is commonly referred to as a delta-mode measurement.

The rest of the data is not highlighted and shows very high resistance instead. This makes sense because for most any two pins, there is no conductive path between them and thus the resistance would be very high. What this test has done is not only measure the resistance of the wires in the cable, but it has also shown the isolation between the pins.

Conclusion

With today's high pin count ICs, contact resistance testing of pin sockets provides some unique challenges for test systems. It can be difficult to build a system that provides enough density to test the whole socket without filling an entire test rack while at the same time maintaining flexibility in how and where these tests are performed. Often times it is possible to create a system that provides the necessary capabilities, but requires the use of overly complicated channel patterns to make connections. This often makes the system both difficult to use as well as difficult to scale to larger applications. Today, this is no longer a problem thanks to new high density matrix cards like the Keithley Model 3732. These cards allow for maximum flexibility and the highest possible density without sacrificing ease of use or scalability. They are truly ready for the next generation of test and measurement applications.

References

1. Edward M. Bock, Jr., *"Low Level Contact Resistance Characterization,"* AMP Journal of Technology Vol. 3 November, 1993
2. Intel Corporation, *"Intel® Pentium® 4 Processor 478-Pin Socket (mPGA478),"* Design Guidelines, October 2001

Appendix A

Model 3732 Application Note Script.tsp

```
--[[
   Title:        3732 App Note Test Script

   Author:       Keithley Applications
   Description:  This script is designed to perform a pin test using a
   3706A with 3732 card and a 2600B Series SMU.  This script will scan the
   pins measuring the resistance between one pin and every other pin on
   an idividual basis.  It will then repeat the process for the next pin
   until every pin has been measured agains every other pin.

   This script requires that the 3732 card be configured as a Single
   4x112 matrix and that the card be placed in slot 1 of the 3706A
   mainframe.  This script requires that the Hi and Lo leads of the 2600B
   SMU be connected to analog backplane 4 through the backplane connector
   on the back of the 3706A mainframe.

   Hardware Requirements:
   1x 2600B Series SourceMeter Instrument
   1x 3706A System Switch/Multimeter
   1x 3723 Quad 4x28 Matrix card, configured as a Single 4x112
   1x 3732-ST-C Column Expanding Screw Terminal

   Firmware Revisions Used:
   3706A: 1.4
   26XXB: 2.1.1

   Revision History:

   REV 1.0.0,  3/18/2010
   Modified by:  Keithley Applications
   Original Revision
]]--


-- This function performs the pin test entirely in script and does not
-- use the advanced trigger models of the 3706A and 2600B Series SMU.
function PinTestScript(srcLevelI, measRngV, pins)
   if (srcLevelI == nil)        then srcLevelI     = 1e-3  end
   if (measRngV == nil)         then measRngV      = 0.1   end
   if (pins == nil)                     then pins         = 56    end

   InitializeTSP()                      -- Initialize the TSP-Link network

   reset()                              -- reset 2600B
   ke3706.reset()                       -- reset 3706A

   -- Configure the DMM
   ke3706.dmm.func                         = ke3706.dmm.DC_VOLTS
```

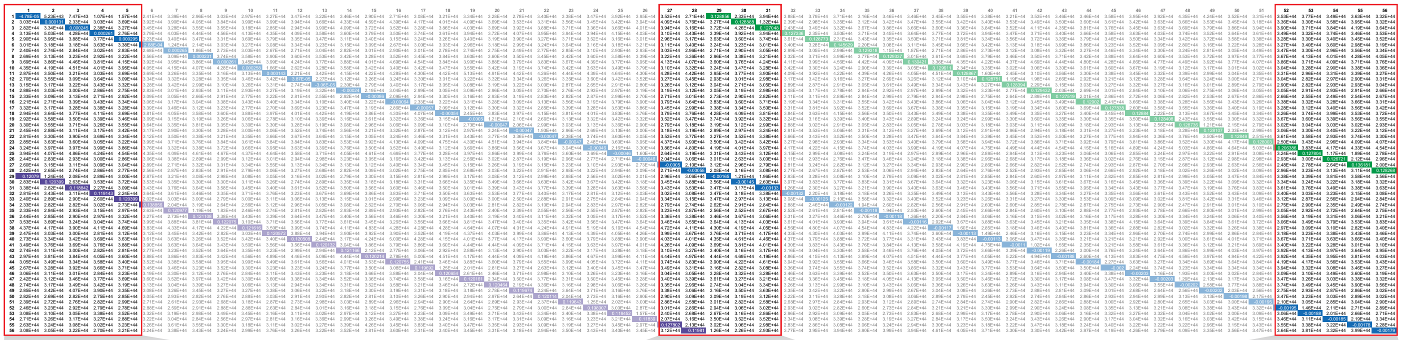
```
   ke3706.dmm.autorange          = 0
   ke3706.dmm.range                       = measRngV
   ke3706.dmm.nplc                          = 1
   print(“DMM Settings Configured”)

   -- Configure the SMU
   smua.reset()
   smua.source.func                         = smua.OUTPUT_DCAMPS
   smua.source.autorangei                 = 0
   smua.measure.autorangei                = 0
   smua.measure.autorangev                = 0
   smua.source.rangei                       = srcLevelI
   smua.measure.rangei                      = srcLevelI
   smua.measure.nplc                        = 1
   print(“SMU Settings Configured”)

   -- Create a reading buffer for the dmm
   rbuf                          = ke3706.dmm.makebuffer(pins*pins)
   rbuf.clear()
   rbuf.appendmode                        = 1

   -- Configure the SMU reading buffer
   smua.nvbuffer1.clear()
   smua.nvbuffer1.appendmode     = 1
   print(“Reading Buffers Ready”)

   -- Begin Test
   print(“Test Running...”)
   display.clear()
   ke3706.display.clear()
   display.settext(“Test in Progress!”)
   ke3706.display.settext(“Do NOT Disturb!”)
   smua.source.output = 1

   for i=1,pins do                        -- HI Pin
      for j=1,pins do            -- LO Pin

--       print(string.format(“From:\t%d\tTo:\t%d”, i, j))
         chList = ke3706.channel.createspecifier(1,1,1,2*(i-1)+2) .. ‘,’ .. ke3706.channel.createspecifier(1,1
,3,2*(i-1)+1) .. ‘,’ .. ke3706.channel.createspecifier(1,1,2,2*(j-1)+2) .. ‘,’ .. ke3706.channel.createspecifi
er(1,1,4,2*(j-1)+1) .. “,10911,10914”
         ke3706.channel.exclusiveclose(chList)
         smua.source.leveli                         = srcLevelI
         delay(500e-6)                     -- Let the source settle for 500 microseconds
         smua.measure.overlappedi(smua.nvbuffer1)
         ke3706.dmm.measure(rbuf)
         waitcomplete()
         smua.source.leveli                         = 0
      end-- LO Pin
   end   -- HI Pin

   smua.source.output = 0
   print(“Test Complete”)
   display.screen                           = 0
   ke3706.display.screen         = 1

   -- Open Backplane Relays
   ke3706.channel.open(“allslots”)

   -- Print back data
   x = 1
   for i=1,pins do
      line = “”
      for j=1,pins do
         line = line .. rbuf[x]/smua.nvbuffer1[x] .. ‘\t’
         x = x + 1
      end
      print(line)
   end
end


-- This funtion performs the pin test by combining a scan on the 3706A
-- with a sweep on the 2600B Series SMU and synchronizes them with the
```

```
-- instruments’ trigger model.
function PinTestScan(srcLevelI, measRngV, pins)
   if (srcLevelI == nil)         then srcLevelI     = 1e-3 end
   if (measRngV == nil)          then measRngV      = 0.1  end
   if (pins == nil)                       then pins         = 56   end

   InitializeTSP()                        -- Initialize the TSP-Link network

   reset()                                -- reset 2600B
   ke3706.reset()                         -- reset 3706A
   ke3706.scan.reset()           -- Clear the scan list

   -- Create a DMM config for the scan
   ke3706.dmm.func                          = ke3706.dmm.DC_VOLTS
   ke3706.dmm.autorange          = 0
   ke3706.dmm.range                       = measRngV
   ke3706.dmm.nplc                          = 1
   ke3706.dmm.configure.set(“PinTestConfig”)
   print(“DMM Settings Configured”)

   -- Configure the SMU settings
   smua.reset()
   smua.source.func                         = smua.OUTPUT_DCAMPS
   smua.source.autorangei                 = 0
   smua.measure.autorangei                = 0
   smua.measure.autorangev                = 0
   smua.source.rangei                       = srcLevelI
   smua.measure.rangei                      = srcLevelI
   smua.source.delay                        = 500e-6              -- Set a source delay to allow signal to
settle
    print(“SMU Settings Configured”)

   -- Configure trigger models
   --==============================
   -- Configure 3706A Trigger Model
   ---------------------------------------------
   ke3706.tsplink.trigger[1].mode                  = ke3706.tsplink.TRIG_SYNCHRONOUSA
   ke3706.tsplink.trigger[1].stimulus       = ke3706.scan.trigger.EVENT_CHANNEL_READY
   ke3706.tsplink.trigger[1].clear()

   ke3706.tsplink.trigger[2].mode                  = ke3706.tsplink.TRIG_SYNCHRONOUSA
   ke3706.tsplink.trigger[2].stimulus       = ke3706.scan.trigger.EVENT_SEQUENCE_COMP
   ke3706.tsplink.trigger[2].clear()

   ke3706.scan.trigger.channel.stimulus   = ke3706.tsplink.trigger[1].EVENT_ID
   ke3706.scan.trigger.channel.clear()

   ke3706.scan.trigger.sequence.stimulus  = ke3706.tsplink.trigger[2].EVENT_ID
   ke3706.scan.trigger.sequence.clear()

   ke3706.scan.bypass = 0
   ---------------------------------------------
   print(“3706A Trigger Model Configured”)


   -- Configure 2600B Trigger Mode
   ------------------------------------------
   tsplink.trigger[1].mode                         = tsplink.TRIG_SYNCHRONOUSM
   tsplink.trigger[1].stimulus              = smua.trigger.PULSE_COMPLETE_EVENT_ID
   tsplink.trigger[1].clear()

   tsplink.trigger[2].mode                         = tsplink.TRIG_SYNCHRONOUSM
   tsplink.trigger[2].stimulus              = smua.trigger.SOURCE_COMPLETE_EVENT_ID
   tsplink.trigger[2].clear()

   smua.trigger.source.lineari(srcLevelI, srcLevelI, 2)    -- Config Linear Sweep V
   smua.trigger.source.limitv               = 1
   smua.trigger.measure.action              = smua.ENABLE
   smua.trigger.measure.i(smua.nvbuffer1)
   smua.trigger.endpulse.action           = smua.SOURCE_IDLE
   smua.trigger.endsweep.action           = smua.SOURCE_IDLE
   smua.trigger.count                                     = pins*pins
   smua.trigger.arm.stimulus                = 0
   smua.trigger.source.stimulus           = tsplink.trigger[1].EVENT_ID
```

```
   smua.trigger.measure.stimulus          = 0
   smua.trigger.endpulse.stimulus           = tsplink.trigger[2].EVENT_ID
   smua.trigger.source.action               = smua.ENABLE         -- Turn on sweeps
   --------------------------------------------
   --============================
   print(“26XXB Trigger Model Configured”)


   -- Build A Scan List
   --****************
   -- Each step in the scan will need to close multiple crosspoints to complete
   -- the connections between the instruments and the test pins.  We could do
   -- this by creating patterns and then adding the patterns to the scan using
   -- the command scan.add() however, since pattern memory is limited and we
   -- don’t need to save these patterns since they are easy to generate, we will
   -- use scan.adimagestep() instead.
   print(“Building Scan List...”)
   for i=1,pins do                        -- HI Pin Loop
      for j=1,pins do            -- LO Pin Loop
         chList = ke3706.channel.createspecifier(1,1,1,2*(i-1)+2) .. ‘,’ .. ke3706.channel.createspecifier(1,1
,3,2*(i-1)+1) .. ‘,’ .. ke3706.channel.createspecifier(1,1,2,2*(j-1)+2) .. ‘,’ .. ke3706.channel.createspecifi
er(1,1,4,2*(j-1)+1) .. “,10911,10914”

         ke3706.scan.addimagestep(chList, “PinTestConfig”)

         if (errorqueue.count > 0) then
             print(“Error while configuring scan.  Exiting test.”)
             exit()
         end
      end
   end
   --*****************
   -- End Build Scan List

   print(string.format(“Scan List built.  Scan has %d steps.”, ke3706.scan.stepcount))
   collectgarbage()

   -- Create a reading buffer for the scan
   rbuf                          = ke3706.dmm.makebuffer(ke3706.scan.stepcount)
   rbuf.clear()
   rbuf.appendmode               = 1

   -- Configure the SMU reading buffer
   smua.nvbuffer1.clear()
   smua.nvbuffer1.collectsourcevalues     = 1
   smua.nvbuffer2.clear()
   smua.nvbuffer2.collectsourcevalues     = 1
   print(“Reading Buffers Ready”)


   -- Initiate scan
   -------------------
   print(“Running Scan”)
   display.clear()
   ke3706.display.clear()
   display.settext(“Test in Progress!”)
   ke3706.display.settext(“Do NOT Disturb!”)
   smua.source.output = 1

   ke3706.scan.background(rbuf)  -- Inititate the 3706A trigger model
   smua.trigger.initiate()                  -- Initiate the 2600B trigger model

   delay(0.1)                                              -- Give the trigger models a little time to
synchronize
   tsplink.trigger[1].assert()            -- This trigger puts the scan in motion
   waitcomplete()

   smua.source.output = 0
   print(“Scan Done”)
   display.screen                           = 0
   ke3706.display.screen         = 1

   -- Open Backplane Relays
   ke3706.channel.open(“allslots”)
```

```
   -- Print Back Data
   x = 1
   for i=1,pins do
      line = “”
      for j=1,pins do
         line = line .. rbuf[x]/smua.nvbuffer1[x] .. ‘\t’
         x = x + 1
      end
      print(line)
   end
end


-- This function initializes the TSP network for this script and creates an alias for the 3706A
function InitializeTSP()
   errorqueue.clear()
   if (tsplink.state ~= “online”) then
      tsplink.reset(2)

      if (errorqueue.count > 0) then
         print(errorqueue.next())
         exit()
      end
   end
   ke3706    = node[2]           -- Create Alias
end
```

Appendix B: Data Collected During Example Test



	1	2	3	4	5
1	-4.78E-05	5.23E+43	7.47E+43	1.07E+44	1.57E+44
2	3.03E+44	0.000131	2.33E+44	3.03E+44	3.69E+44
3	2.82E+44	3.34E+44	0.000245	2.38E+44	3.27E+44
4	3.13E+44	5.03E+44	4.28E+44	0.000261	2.76E+44
5	2.90E+44	3.95E+44	3.88E+44	3.77E+44	0.000295
6	3.01E+44	3.18E+44	3.18E+44	3.63E+44	3.38E+44
7	2.40E+44	2.74E+44	2.84E+44	3.02E+44	2.83E+44
8	2.69E+44	3.13E+44	3.23E+44	2.92E+44	3.22E+44
9	3.69E+44	3.86E+44	4.46E+44	3.81E+44	4.15E+44
10	4.35E+44	4.19E+44	4.51E+44	4.01E+44	3.95E+44
11	2.87E+44	3.50E+44	3.21E+44	3.03E+44	3.69E+44
12	2.70E+44	3.55E+44	3.09E+44	3.64E+44	3.09E+44
13	3.15E+44	3.17E+44	3.22E+44	3.43E+44	3.32E+44
14	2.88E+44	3.03E+44	3.00E+44	2.86E+44	2.75E+44
15	2.33E+44	3.09E+44	3.13E+44	2.71E+44	2.92E+44
16	2.21E+44	2.71E+44	3.39E+44	3.43E+44	3.34E+44
17	3.32E+44	3.17E+44	3.28E+44	3.38E+44	3.28E+44
18	2.94E+44	3.64E+44	3.77E+44	4.11E+44	3.69E+44
19	2.92E+44	3.58E+44	3.50E+44	3.39E+44	3.46E+44
20	3.30E+44	3.55E+44	3.71E+44	3.26E+44	3.55E+44
21	2.45E+44	2.88E+44	3.11E+44	3.17E+44	3.42E+44
22	2.81E+44	3.30E+44	3.90E+44	3.69E+44	3.34E+44
23	2.85E+44	3.63E+44	3.60E+44	3.05E+44	3.22E+44
24	3.24E+44	3.97E+44	3.97E+44	3.99E+44	3.86E+44
25	3.94E+44	4.07E+44	4.86E+44	4.24E+44	4.54E+44
26	2.44E+44	2.83E+44	2.93E+44	3.00E+44	2.86E+44
27	2.60E+44	3.15E+44	3.11E+44	3.09E+44	3.04E+44
28	2.42E+44	2.65E+44	2.74E+44	2.86E+44	2.77E+44
29	0.12079	1.24E+44	2.08E+44	2.89E+44	3.00E+44
30	2.83E+44	0.120399	2.63E+44	3.53E+44	3.72E+44
31	3.38E+44	2.62E+44	0.118842	2.27E+44	3.09E+44
32	2.81E+44	3.43E+44	3.11E+44	0.119143	2.24E+44
33	2.40E+44	2.89E+44	2.90E+44	2.60E+44	0.120399
34	2.33E+44	2.82E+44	2.82E+44	3.02E+44	2.73E+44
35	2.33E+44	2.84E+44	2.93E+44	3.15E+44	2.97E+44
36	2.44E+44	2.85E+44	2.90E+44	2.97E+44	3.32E+44
37	3.53E+44	3.69E+44	3.24E+44	3.04E+44	3.74E+44
38	4.37E+44	4.17E+44	3.90E+44	4.11E+44	4.69E+44
39	2.47E+44	3.03E+44	3.00E+44	2.81E+44	3.12E+44
40	2.73E+44	3.34E+44	3.42E+44	3.69E+44	3.63E+44
41	3.49E+44	3.76E+44	3.69E+44	3.76E+44	3.88E+44
42	2.74E+44	3.11E+44	3.00E+44	2.82E+44	2.81E+44
43	2.97E+44	3.81E+44	3.84E+44	4.05E+44	3.60E+44
44	3.05E+44	3.49E+44	3.34E+44	3.58E+44	3.40E+44
45	2.67E+44	3.28E+44	3.92E+44	3.66E+44	3.71E+44
46	3.06E+44	3.11E+44	3.01E+44	2.84E+44	3.23E+44
47	2.42E+44	3.12E+44	3.46E+44	3.77E+44	3.69E+44
48	2.74E+44	3.17E+44	3.49E+44	3.42E+44	3.19E+44
49	2.85E+44	3.42E+44	4.07E+44	3.90E+44	3.35E+44
50	2.82E+44	2.69E+44	2.82E+44	2.75E+44	2.85E+44
51	2.39E+44	2.72E+44	2.76E+44	2.82E+44	2.99E+44
52	2.46E+44	3.23E+44	2.92E+44	2.79E+44	2.78E+44
53	3.08E+44	3.10E+44	3.05E+44	3.38E+44	3.52E+44
54	2.71E+44	3.26E+44	3.17E+44	3.27E+44	2.88E+44
55	2.63E+44	3.24E+44	3.08E+44	3.02E+44	3.23E+44
56	3.08E+44	3.05E+44	3.22E+44	2.70E+44	3.21E+44

27	28	29	30	31
3.53E+44	2.71E+44	0.128856	2.33E+44	3.94E+44
4.09E+44	3.76E+44	3.27E+44	0.128888	1.32E+44
3.94E+44	3.16E+44	3.72E+44	4.26E+44	0.127048
3.10E+44	3.43E+44	3.39E+44	3.92E+44	3.94E+44
2.96E+44	3.17E+44	3.63E+44	3.60E+44	3.74E+44
3.11E+44	3.40E+44	3.24E+44	3.23E+44	3.01E+44
3.03E+44	2.96E+44	2.71E+44	2.90E+44	3.05E+44
3.22E+44	3.36E+44	2.96E+44	3.38E+44	3.21E+44
4.13E+44	4.07E+44	3.60E+44	3.76E+44	4.24E+44
3.10E+44	3.32E+44	3.24E+44	3.47E+44	3.28E+44
4.28E+44	4.42E+44	3.95E+44	3.77E+44	3.90E+44
3.27E+44	3.45E+44	2.93E+44	3.01E+44	2.98E+44
3.26E+44	3.12E+44	3.04E+44	2.71E+44	3.05E+44
3.19E+44	3.12E+44	3.05E+44	3.19E+44	2.98E+44
2.71E+44	3.01E+44	2.73E+44	2.90E+44	2.82E+44
3.79E+44	3.64E+44	3.83E+44	3.60E+44	3.71E+44
3.45E+44	2.99E+44	3.38E+44	3.34E+44	3.50E+44
3.79E+44	3.76E+44	4.28E+44	4.09E+44	3.81E+44
3.52E+44	3.47E+44	3.74E+44	3.92E+44	3.32E+44
2.79E+44	3.18E+44	3.19E+44	3.12E+44	2.99E+44
3.18E+44	3.19E+44	2.99E+44	2.97E+44	3.24E+44
3.53E+44	3.77E+44	3.27E+44	3.53E+44	3.38E+44
4.37E+44	3.90E+44	3.50E+44	3.42E+44	3.42E+44
3.86E+44	4.80E+44	4.19E+44	4.01E+44	3.97E+44
2.64E+44	3.19E+44	3.31E+44	3.43E+44	3.12E+44
2.04E+44	3.06E+44	3.01E+44	2.63E+44	3.00E+44
-0.0005	2.10E+44	3.12E+44	2.96E+44	2.79E+44
2.71E+44	-0.00058	2.08E+44	3.16E+44	3.08E+44
2.96E+44	3.06E+44	-0.00165	1.21E+44	1.96E+44
3.45E+44	3.88E+44	3.56E+44	-0.00145	2.60E+44
3.43E+44	3.53E+44	3.47E+44	3.17E+44	-0.00133
3.02E+44	3.08E+44	3.47E+44	3.18E+44	3.38E+44
3.34E+44	3.15E+44	3.47E+44	2.97E+44	3.13E+44
2.79E+44	2.74E+44	2.62E+44	2.91E+44	2.84E+44
3.23E+44	2.87E+44	2.56E+44	2.52E+44	2.67E+44
3.36E+44	3.38E+44	3.46E+44	3.67E+44	3.06E+44
3.46E+44	3.55E+44	3.64E+44	4.13E+44	4.03E+44
4.72E+44	4.11E+44	4.30E+44	4.19E+44	4.05E+44
3.99E+44	3.67E+44	3.76E+44	3.71E+44	4.17E+44
4.03E+44	4.01E+44	4.35E+44	4.61E+44	4.46E+44
4.26E+44	4.09E+44	3.69E+44	3.81E+44	4.01E+44
3.10E+44	3.27E+44	3.40E+44	3.16E+44	3.17E+44
4.44E+44	4.97E+44	4.44E+44	4.69E+44	4.19E+44
3.74E+44	3.83E+44	3.90E+44	4.22E+44	4.61E+44
3.49E+44	3.31E+44	3.16E+44	2.82E+44	3.08E+44
3.04E+44	3.05E+44	3.28E+44	3.32E+44	3.28E+44
3.40E+44	3.39E+44	3.61E+44	3.27E+44	3.21E+44
3.35E+44	2.96E+44	2.74E+44	3.04E+44	3.34E+44
3.38E+44	3.06E+44	3.16E+44	3.50E+44	3.63E+44
2.90E+44	3.09E+44	3.09E+44	3.19E+44	3.12E+44
2.86E+44	2.58E+44	3.01E+44	2.82E+44	2.58E+44
3.01E+44	2.86E+44	2.94E+44	3.06E+44	3.02E+44
2.40E+44	2.68E+44	2.67E+44	3.16E+44	2.86E+44
2.07E+44	3.16E+44	3.50E+44	3.52E+44	3.52E+44
0.127802	2.13E+44	3.02E+44	3.06E+44	2.98E+44
3.12E+44	0.11981	1.26E+44	2.26E+44	2.93E+44

52	53	54	55	56
3.53E+44	3.77E+44	3.49E+44	3.63E+44	3.32E+44
3.36E+44	3.30E+44	3.58E+44	3.95E+44	3.32E+44
3.90E+44	3.71E+44	3.84E+44	4.19E+44	3.64E+44
3.49E+44	3.32E+44	3.74E+44	3.46E+44	3.53E+44
3.28E+44	3.30E+44	3.40E+44	3.45E+44	3.52E+44
3.27E+44	3.40E+44	3.60E+44	2.98E+44	3.19E+44
3.47E+44	3.30E+44	2.96E+44	3.56E+44	3.34E+44
3.67E+44	4.13E+44	4.01E+44	4.28E+44	4.05E+44
3.86E+44	3.71E+44	4.09E+44	3.71E+44	3.76E+44
3.04E+44	3.28E+44	2.90E+44	3.38E+44	3.36E+44
3.31E+44	2.96E+44	3.31E+44	3.39E+44	3.27E+44
3.04E+44	2.82E+44	2.97E+44	2.90E+44	3.31E+44
2.90E+44	2.82E+44	2.93E+44	2.93E+44	3.04E+44
3.05E+44	2.91E+44	2.93E+44	2.91E+44	2.66E+44
2.66E+44	2.55E+44	2.49E+44	2.54E+44	2.67E+44
3.38E+44	3.32E+44	3.28E+44	3.66E+44	3.31E+44
3.28E+44	3.12E+44	3.40E+44	3.56E+44	3.42E+44
3.26E+44	3.74E+44	3.99E+44	3.53E+44	3.72E+44
3.67E+44	3.60E+44	3.39E+44	3.56E+44	3.55E+44
3.02E+44	3.04E+44	3.03E+44	3.02E+44	2.93E+44
3.06E+44	3.30E+44	3.40E+44	3.22E+44	3.12E+44
3.61E+44	3.58E+44	2.93E+44	3.74E+44	3.30E+44
2.50E+44	3.43E+44	2.96E+44	4.09E+44	4.07E+44
0.206386	3.83E+44	4.17E+44	4.33E+44	4.54E+44
3.24E+44	0.127804	1.17E+44	1.89E+44	2.78E+44
2.93E+44	3.00E+44	0.126721	2.12E+44	2.96E+44
2.48E+44	2.78E+44	2.64E+44	0.136181	2.00E+44
2.96E+44	3.23E+44	3.13E+44	3.11E+44	0.128268
3.38E+44	3.39E+44	3.81E+44	3.58E+44	3.56E+44
3.34E+44	3.24E+44	3.22E+44	3.18E+44	3.32E+44
3.61E+44	3.76E+44	3.49E+44	3.38E+44	3.63E+44
3.40E+44	3.03E+44	3.23E+44	3.15E+44	3.08E+44
3.12E+44	2.87E+44	2.56E+44	2.94E+44	2.84E+44
2.75E+44	2.90E+44	2.35E+44	2.49E+44	2.74E+44
3.05E+44	2.92E+44	2.72E+44	2.64E+44	2.75E+44
3.56E+44	3.19E+44	3.31E+44	3.06E+44	3.21E+44
3.06E+44	3.49E+44	3.79E+44	3.53E+44	3.83E+44
2.97E+44	3.09E+44	3.10E+44	2.82E+44	3.40E+44
3.18E+44	3.23E+44	3.38E+44	3.43E+44	3.46E+44
3.67E+44	3.71E+44	3.63E+44	3.66E+44	3.40E+44
3.40E+44	3.22E+44	3.28E+44	3.01E+44	3.10E+44
3.92E+44	4.13E+44	3.97E+44	3.64E+44	3.95E+44
3.92E+44	4.35E+44	3.95E+44	3.81E+44	4.03E+44
4.19E+44	4.17E+44	3.56E+44	3.53E+44	3.43E+44
3.94E+44	3.32E+44	3.08E+44	3.46E+44	3.27E+44
3.09E+44	3.10E+44	3.49E+44	3.60E+44	3.19E+44
3.47E+44	3.26E+44	3.03E+44	3.38E+44	3.32E+44
3.74E+44	3.49E+44	3.45E+44	3.90E+44	3.56E+44
2.75E+44	2.93E+44	2.87E+44	2.86E+44	3.02E+44
3.47E+44	3.23E+44	3.03E+44	2.89E+44	3.02E+44
2.10E+44	3.05E+44	2.85E+44	3.04E+44	2.90E+44
-0.00195	1.46E+44	2.11E+44	2.71E+44	2.89E+44
3.06E+44	-0.00188	2.01E+44	2.66E+44	2.71E+44
3.46E+44	3.11E+44	-0.00185	2.19E+44	3.34E+44
3.55E+44	3.38E+44	3.22E+44	-0.00178	2.28E+44
3.64E+44	3.81E+44	3.32E+44	3.99E+44	-0.00179

This figure shows the collected resistance values between each of the 56 pins used in a 28-conductor cable test. Pins 1 through 28 were connected to one end of the cable conductors while pins 29 through 56 were connected to the other end. The columns represent the position of the HI test pin while the rows represent the position of the LO test pin. The data is highlighted where the measured resistance value between the pins is low.

🟩 **A.** The highlighted values show the resistance of each conductor from one end of the cable to the other.

🟦 **B**. For the highlighted values, the resistance is low because the HI and LO test pin are the same pin. The value shown is actually a measurement of the resistance of an internal trace in the switch card.

🟪 **C**. The highlighted values also show the resistance of each conductor from one end of the cable to the other. However, the direction of current flow through the conductor was in the opposite direction as the HI and LO pin positions are swapped. Notice how the value in section C is different from the corresponding value in section A. This is due to thermal offsets in the measurement. To get the true resistance value of the conductor, you must average the measurement in section C with the corresponding measurement in section A.

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KEITHLEY INSTRUMENTS, INC. ■ 28775 AURORA RD. ■ CLEVELAND, OH 44139-1891 ■ 440-248-0400 ■ Fax: 440-248-6168 ■ 1-888-KEITHLEY ■ www.keithley.com

BENELUX
+31-40-267-5506
www.keithley.nl

BRAZIL
55-11-4058-0229
www.keithley.com

CHINA
86-10-8447-5556
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FRANCE
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UNITED KINGDOM
+44-1344-39-2450
www.keithley.co.uk

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Printed in the U.S.A

No. 3080

3.24.14