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The Most Common Mistakes Made in Parametric Test*

*And How to Avoid Them

Agilent Technologies

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Mistake #1: Improper triaxial to coaxial adapters

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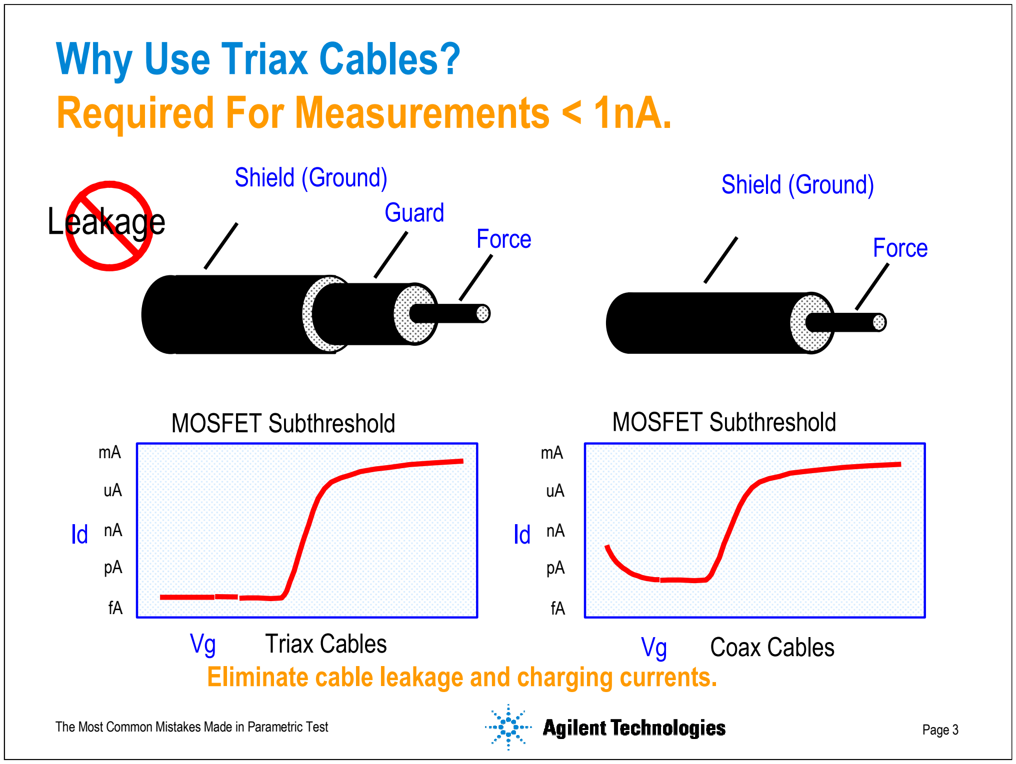


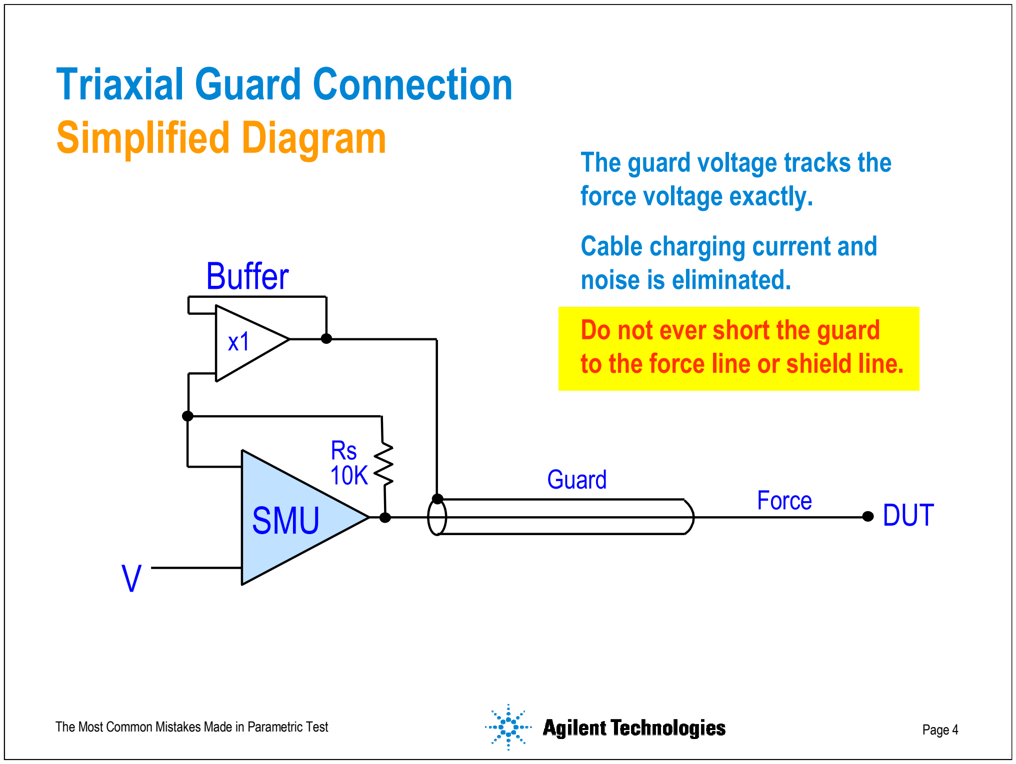
The triax cable is a special low dielectric loss, high impedance cable. This cable may be used down to fA levels when properly used with a guarded probe. The guard voltage tracks the force voltage exactly, so that no voltage drop can exist between guard and force. This eliminates the current leakage that would otherwise limit low current measurements.

If low impedance coax cables are used with outer layer at ground potential, two limitations will be immediately apparent. The cable leakage will limit the low current measurement floor. In addition, when the voltage is swept, the sudden change will cause additional cable charging. This distorts the low current portion of a MOS Subthreshold curve as shown.

RULES:

Unguarded coax cable is OK for measurements above 1nA.

Triax cable or coax with outer layer at guard potential should be used for measurements below 1 nA.



Driven guard isolation is needed for measurements below 1 nA. For measurements below 1 nA, a regular BNC coaxial cable will leak sufficient current between the center conductor and the outer ground shield to affect the accuracy of the measurement.

The driven guard also has the added benefit of improving the measurement speed. The above diagram shows how the cable capacitance is eliminated with a triaxial cable. The guard is driven at the same voltage as the force center conductor. No current can flow between guard and force when they are held at the same potential.

Please note that the guard and force lines are isolated by a buffer amplifier. They should NEVER be shorted together.

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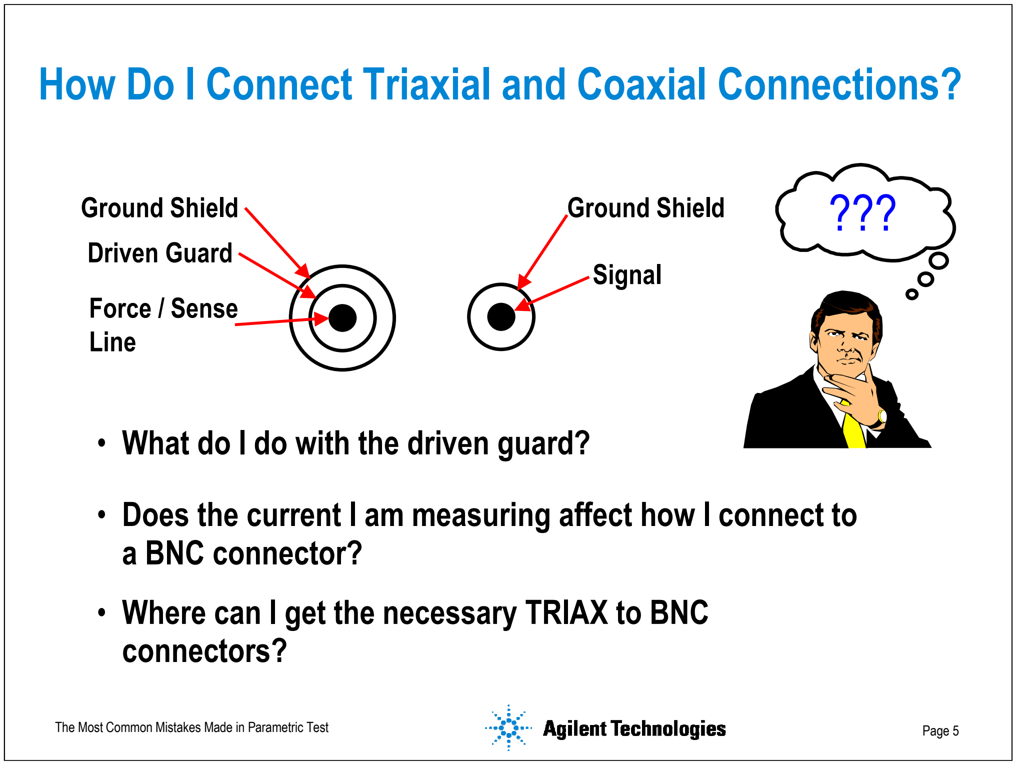
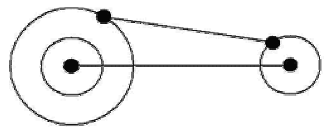


Sometimes it is necessary to connect triaxial cables to coaxial cables. However, doing so raises some questions as to how this connection should be done.

Triaxial to Coaxial Adapters: Measuring Currents > 1 nano-Amp



In this case it is OK to float the guard connection, since current leakage between the center conductor and the outer ground shield does not significantly impact the measurement.

The case where the measured current is above 1 nA is the easiest and simplest. Here you can simply connect the center conductors and outer ground shields together.

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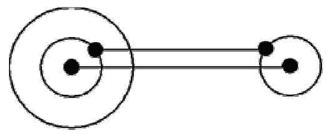
Triaxial to Coaxial Adapters:
Measuring Currents < 1 nano-Amp



Warning! Shock Hazard!

The only way to maintain low-current measurement accuracy in a coaxial environment is to connect the driven guard to the outer shield of the coaxial connector. This presents a potential safety hazard and must be done with great care.

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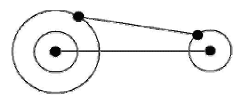
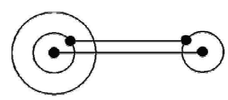
The case where the measured current is less than 1 nA is tricky. There are a couple of things to keep in mind here:

To maintain measurement integrity, the center signal conductor needs to be surrounded by a driven guard. This means that the BNC outer shield cannot be grounded, but instead must be floating. Special connectors and adapters are often needed to accomplish this.

Another important consideration is that the outer BNC shield can be at 100 V (for the case of a HRSMU or MPSMU) or 200 V (for the case of a HPSMU). This presents a potential safety hazard, and requires that great care be taken with the measurement setup to insure that no accidental electrocution can take place.

Summary of Agilent Connectors

Agilent Part Number	Description		
1250-2652	Triax(F) - BNC(M)		Safe. Not suitable for low-current measurements.
1250-2653	Triax(M) - BNC(F)		
Agilent Part Number	**Description**		**WARNING!!!!** **Shock Hazard!!!!** Required for low-current measurements.
1250-2650	Triax(M) - BNC(F)		
1250-2651	Triax(F) - BNC(M)		
1250-1830	Triax(F) - BNC(F)		

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Agilent makes a variety of triaxial to coaxial adapters. In addition, Trompeter also sells these types of adapters as well.

Mistake #2: Connecting SMUs up using the 'Sense' line instead of the 'Force' line

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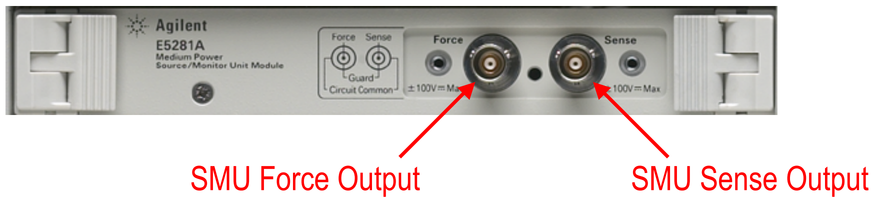
Most SMUs Have Both Force & Sense Outputs – Which Do I Use?



- If making Kelvin measurements, use both the Force and Sense outputs
- If not making Kelvin measurements, always use the Force output (<u>never</u> use the Sense output by itself)

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All Kelvin SMUs have both a Force and a Sense output, but many people are confused as to exactly which connection to use when.

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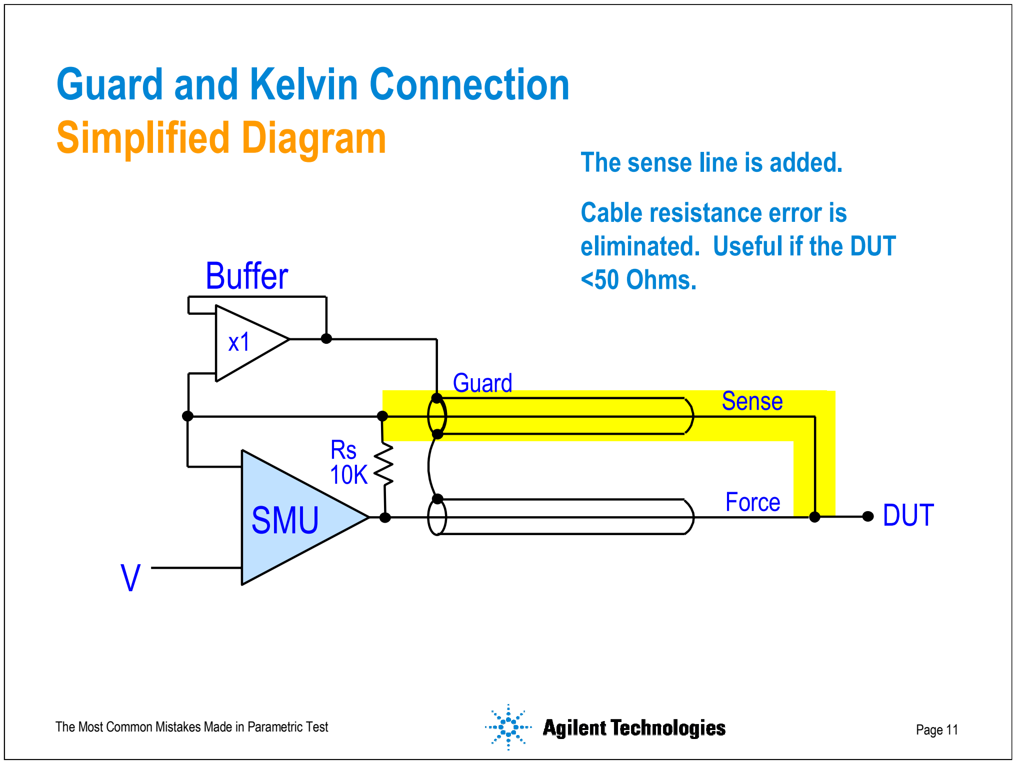
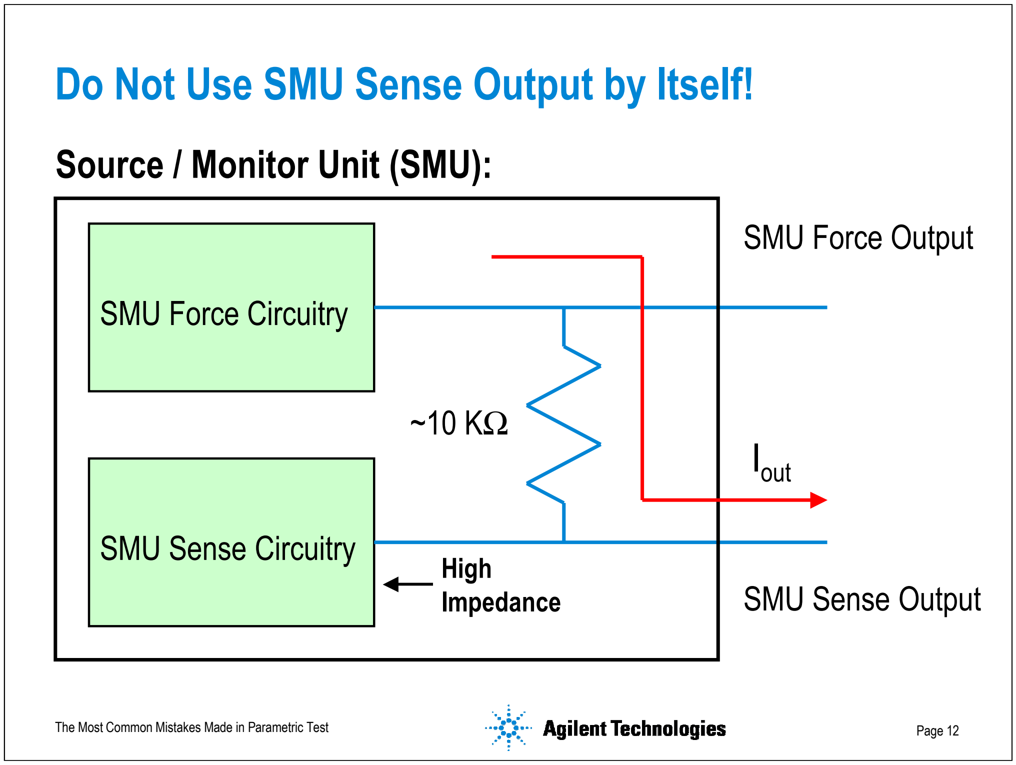


The only difference between the 4155 and 4156 cable configuration is the addition of the sense line. In this case, sensing is done at the DUT, eliminating the fraction of an ohm of cable resistance. The internal sensing resistor Rs is the only feedback path in the 4155.

Note that the 4156 operates just fine without the sense cable. Then it operates just like the 4155. This is important to know because in general you do not need the sensing Kelvin connection. Most MOS measurements are high impedance and the residual cable loss is insignificant.

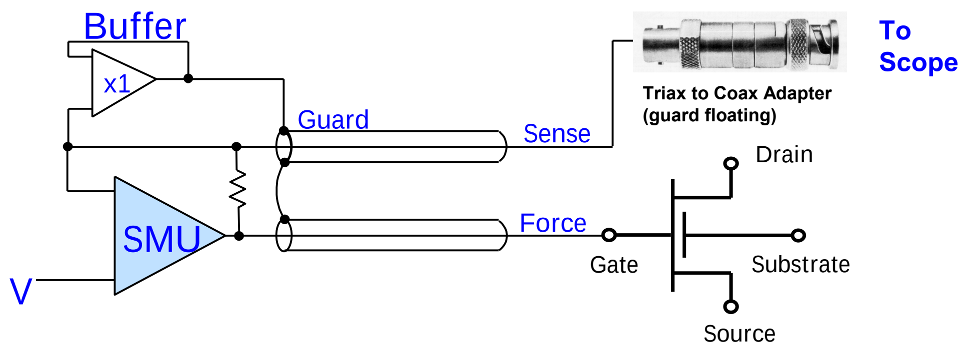
The E5260 Series and E5270B/4157B SMUs are all Kelvin SMUs (just like the 4156C), meaning that they possess both a Force and a Sense output.



If you use the Sense line of a Kelvin SMU only, then all of the force current must pass through the ~ 10 KΩ resistor that connects the Force and Sense lines. This will distort your measurement results.

Note that it is OK to use the Force line by itself. The Sense circuitry is high-impedance, so the ~ 10 KΩ resistor is immaterial to the function of this portion of the SMU circuitry.

Nifty Trick: Use the Sense Line as a High Impedance Scope Probe!



Measure Gate Voltage versus Time Accurately

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The sense line need not be used only for Kelvin connections.

It is ideal for monitoring the voltage on your device with an oscilloscope.

The sense line tracks the force line within 1mv.

All you need is a floating guard coax adapter attached to the sense line at the back of the 4156. Then use any BNC cable to direct connect the SMU sense line to the oscilloscope input.

The adapter shown is the Trompeter Electronics AD-BJ20-E2-PL75.

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Mistake #3: Improper connection on ground unit (GNDU)

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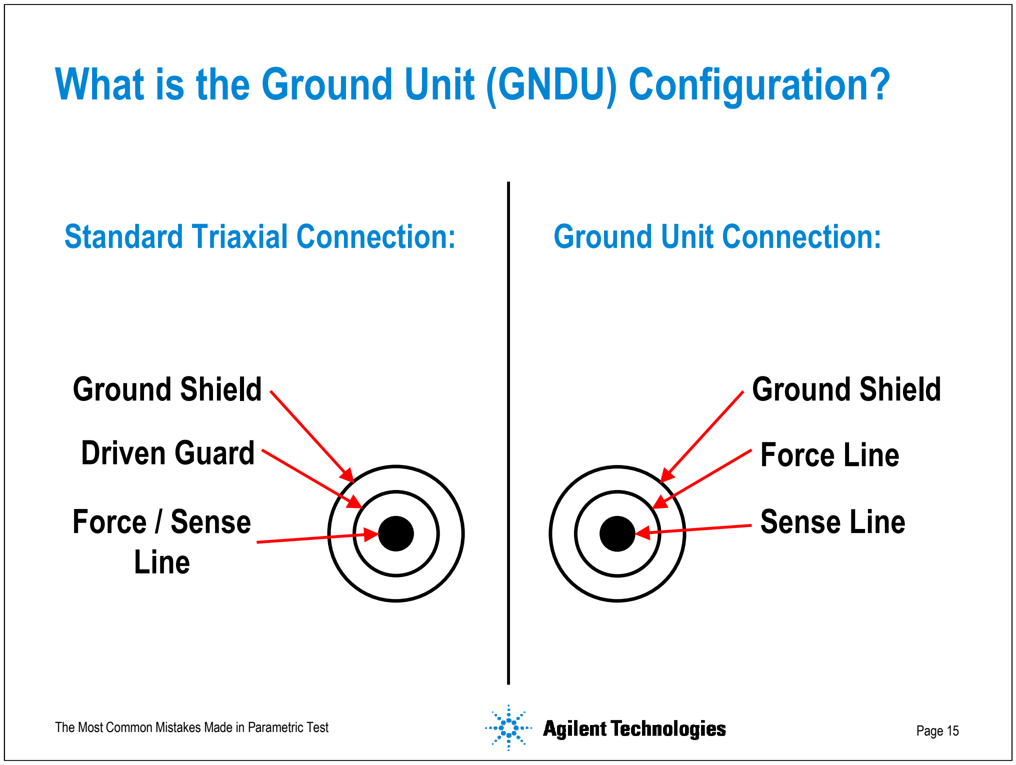
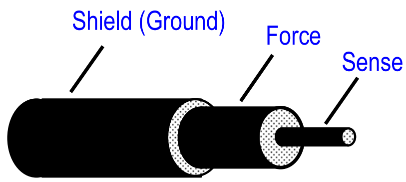


Please look carefully at the above diagrams. Many people do not understand that the ground unit (GNDU), while triaxial, does not have the same configuration as a standard triaxial cable. Failure to connect to the GNDU properly will result in improper measurement results.

Why is the GNDU Configuration the Way It Is?



- **In standard triaxial connections the middle conductor is a driven guard, which eliminates any cable leakage current by always keeping the driven guard the same potential as the center Force/Sense line.**
- **In the case of the ground unit the potential of the Force and Sense lines is always at zero volts, so there is no need to shield it from the outer ground shield to prevent leakage currents.**

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The GNDU is can keep the Force and Sense lines together without a driven guard because the Force and Sense lines are always at 0 Volts potential.

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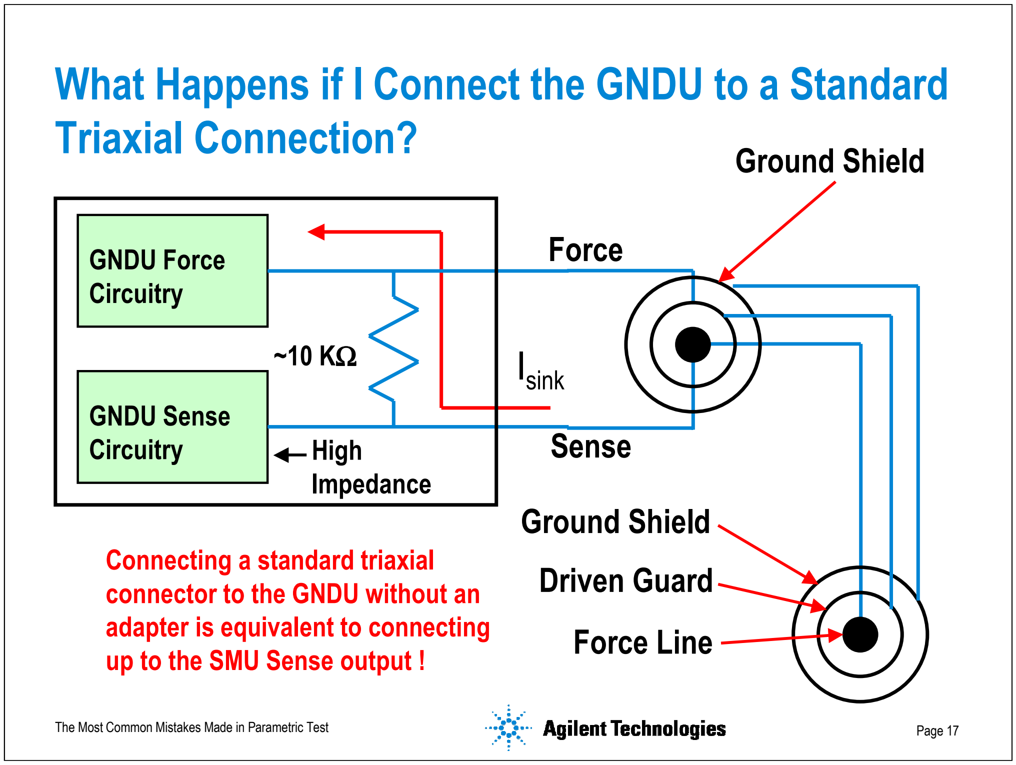
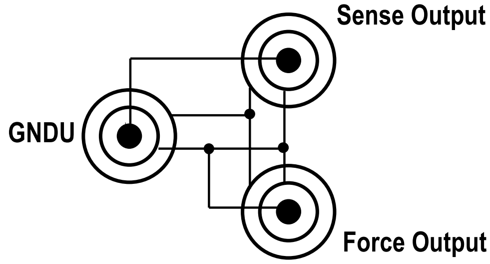


Please note that if you just connect up a triaxial cable to the ground unit without splitting the ground unit's Force and Sense lines into separate connectors, then it is equivalent to connecting up an SMU using only the Sense line!

Proper GNDU Connection

Unless your equipment is designed to handle the GNDU connection, you must use an adapter that splits out the GNDU Force and Sense lines into standard triaxial configurations.



The **Agilent N1254A-100 Ground Unit to Kelvin Adapter** will split the Force and Sense lines into the proper Kelvin configuration.

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Agilent also make a special GNDU to Kelvin Triaxial cable (16493N) that has a triaxial connection on one end, and a Kelvin Triaxial connection on the other. This cable will perform the same function as the ground unit adapter shown above.

Note: The N1254A-100 is designed to be used with the E5260 Series and E5270B/4157B GNDU. However, it can be used with the GNDU found on the 41501A/B expander box for the 4155/4156 by removing the banana plug from the N1254A-100.

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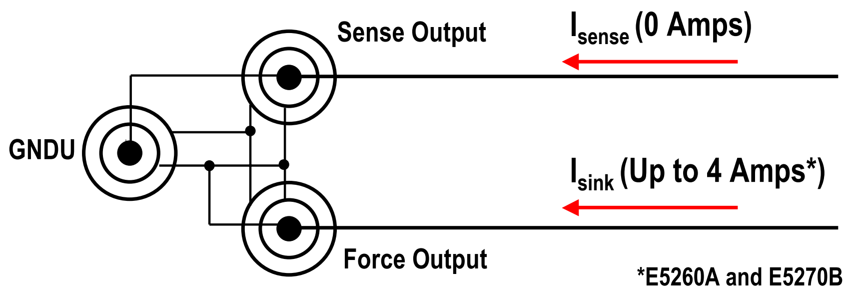
Connections to the GNDU Should be Kelvin

Remember! Pumping large currents through cables will cause an Ohmic drop unless this is compensated via a Kelvin measurement configuration. Since assumedly the reason you are using the GNDU is to sink large currents, you should always connect up both the Force and Sense lines.



*E5260A and E5270B

Note: Agilent makes a special triaxial cable that can handle the 4 Amps of current flow through the GNDU Force output (16493L).

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Mistake #4: Using ‘Limited Auto’ ranging instead of ‘Auto’ ranging

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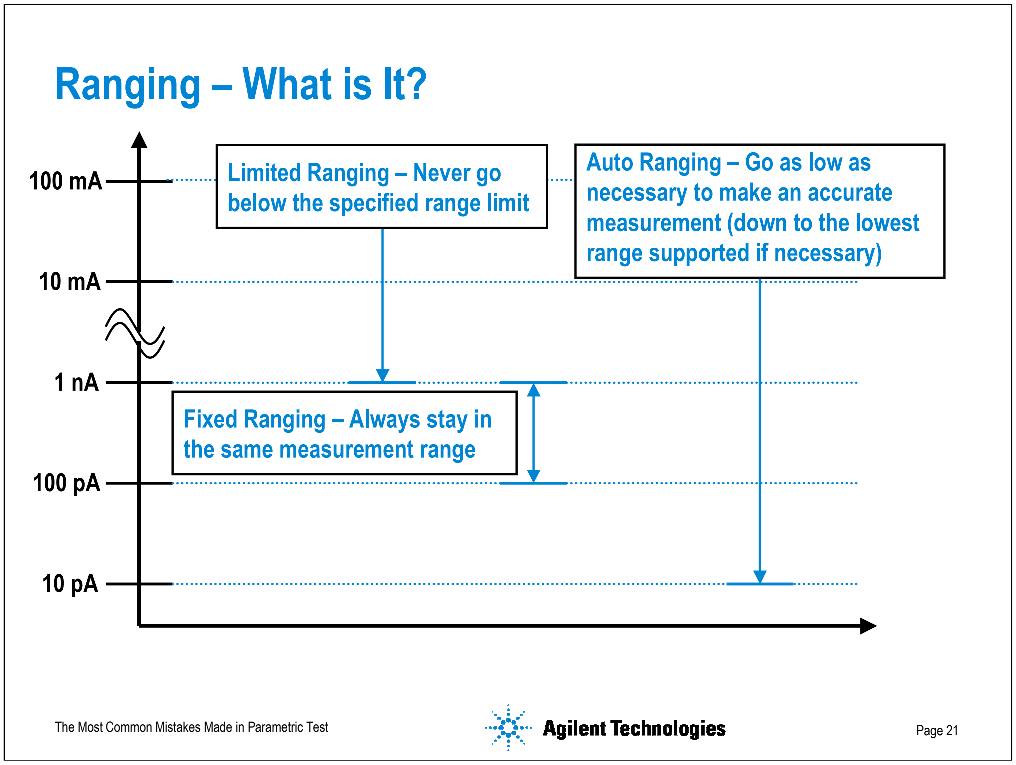
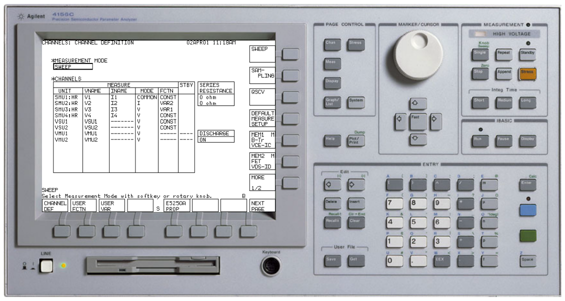


The differences between Fixed, Limited, and Auto ranging are not difficult to understand. However, many people have never had this adequately explained to them.

4156 Example



- **The 4156 has two additional low-current measurement ranges not available on the 4155: 100 pA & 10 pA**
- **The 4156 boots-up like a 4155C (all SMUs set to Limited 1 nA ranging)**
- **Unless these are changed, you cannot get the full low-current measurement capability of the instrument!**

Many people do not understand that the 4156C actually boots up into a state that makes it look like the 4155C! In order to get the additional low-current measurement accuracy of the 4156C, you must change the range settings.

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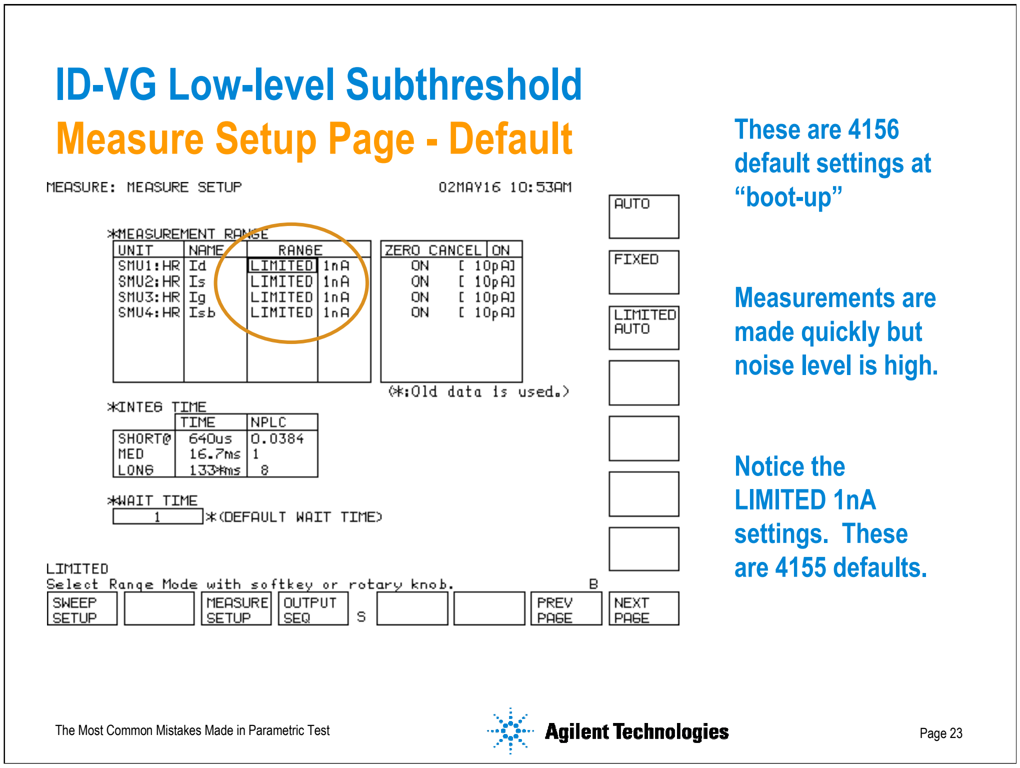
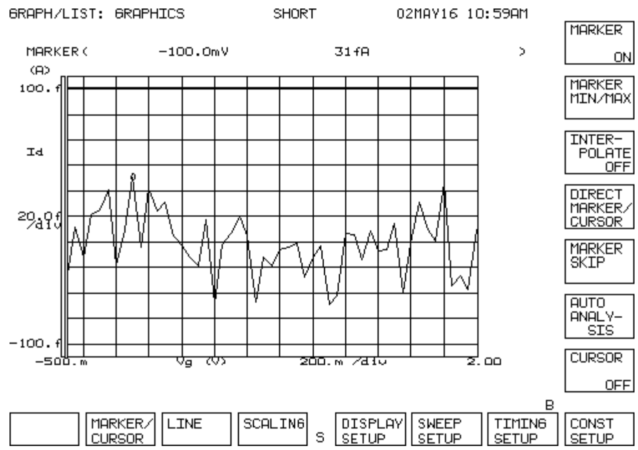


You need to go the “MEASURE SETUP” page of the 4156C.

ID-VG Low-level Subthreshold

Probes Up - Default Range Setting



Noise level is high. Current measurement is limited to the 1nA range.

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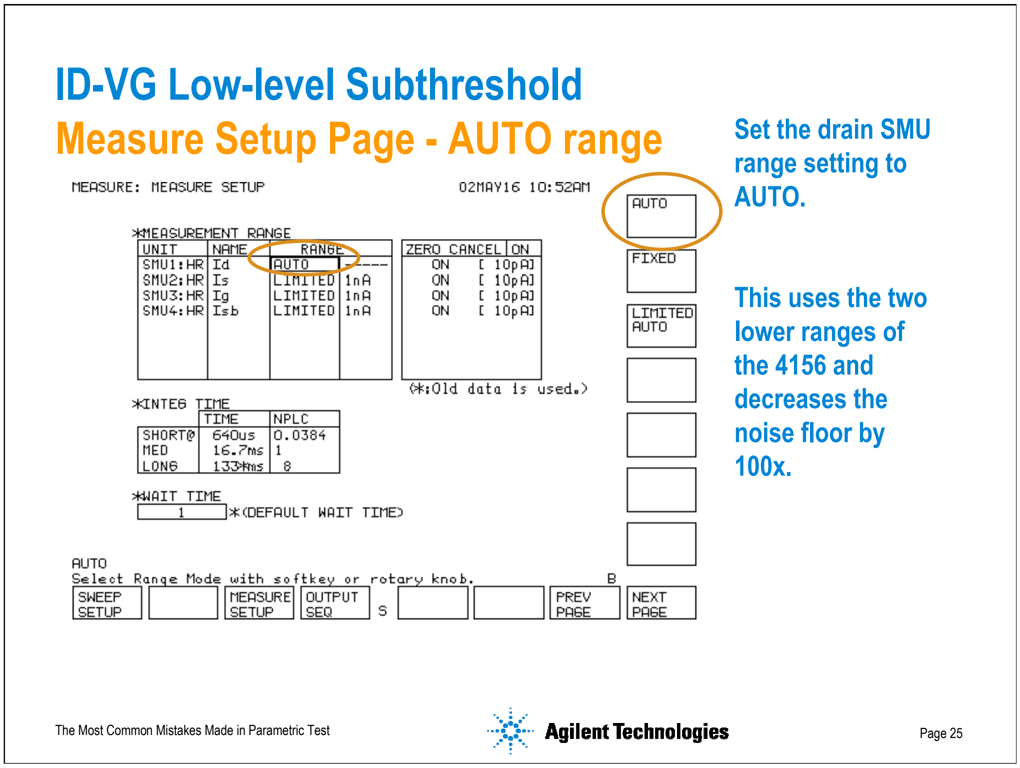
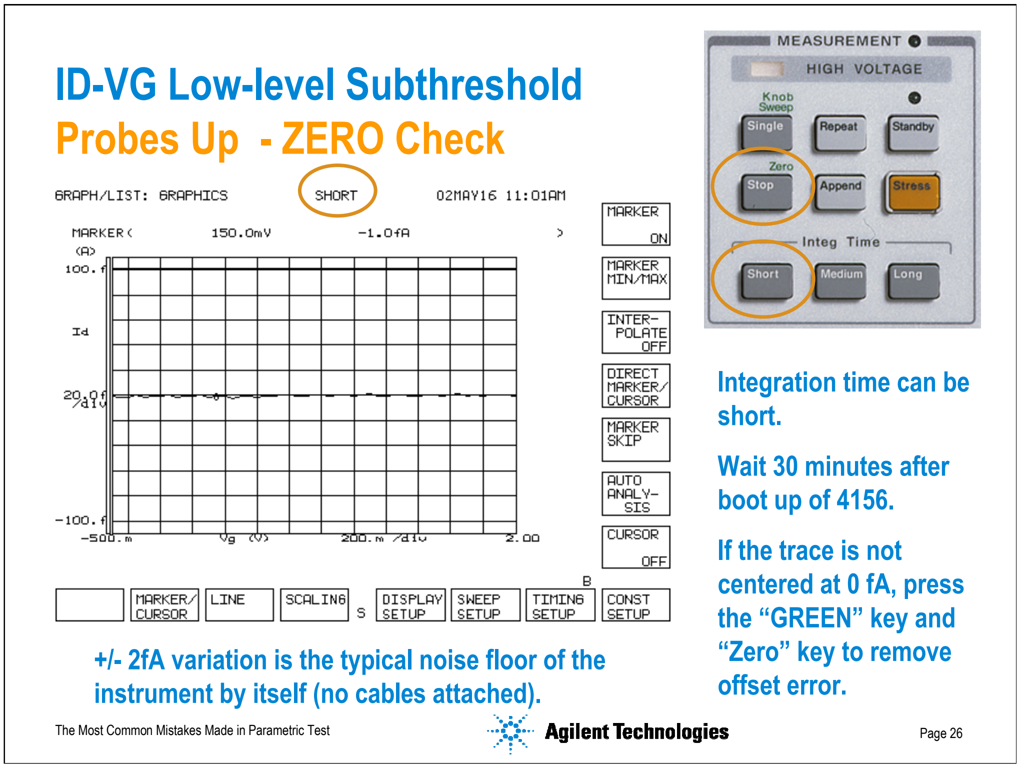
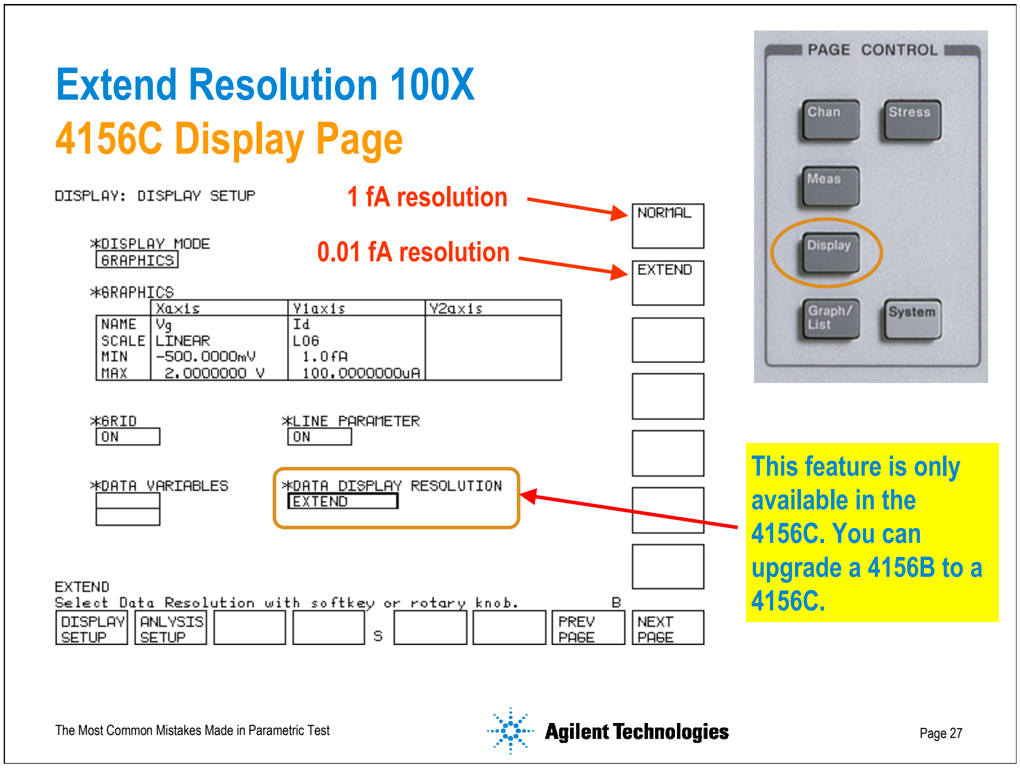
If you keep the boot-up Range settings of the 4156C and try to measure low-current, then you will get results similar to those shown above.



To get the full measurement accuracy of the 4156A/B/C, you need to change the measurement range setting on the SMU actually making the low-current measurement from “LIMITED” to “AUTO”.



For the 4156C, the Range setting has a much greater impact than the integration time. Using AUTO ranging, you should be able to get good low-current measurements most of the time using SHORT integration.

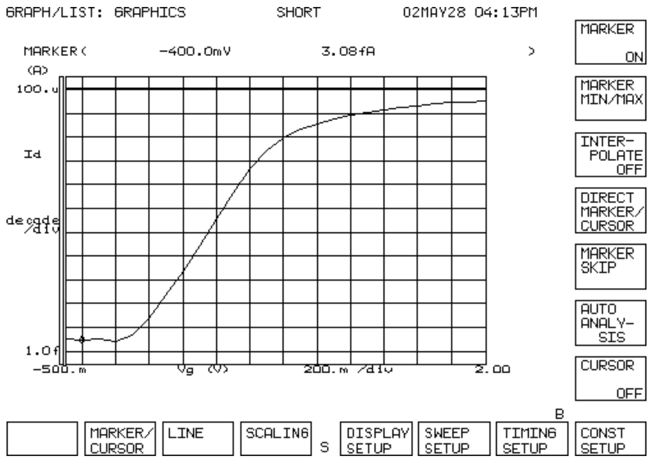


It is possible to extend the measurement resolution of the 4156C to 0.01 fA by changing the parameter setting shown on the “DISPLAY SETUP” page to “EXTEND”. However, this is considered to be “Readable Resolution” as opposed to the instrument’s basic “Resolution”. “Readable Resolution” gives the full resolving capability of the instruments ADC (analog-to-digital converter); however, it does not perform the averaging that is done when you specify simple “Resolution”.

Please note that if you want current measurement resolution better than 1 fA, then the E5270B/4157B high-resolution SMU (HRSMU) does accept an optional atto-sense & switch unit (ASU) capable of achieving true 100 attoamp (0.1 femtoamp) measurement resolution.

ID-VG Low-level Subthreshold Curve

Probes Down - 4156C Graph Page



Low leakage characteristics of a 40 Angstrom thick oxide n-channel MOSFET.

Resolution is .01 fA (10^{-17} Amps)

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This is a sample low-current measurement performed on the 4156C using AUTO ranging.

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Mistake #5: Using Default (Maximum) Current Compliance When Making Measurements in 'Auto' or 'Limited Auto' ranging

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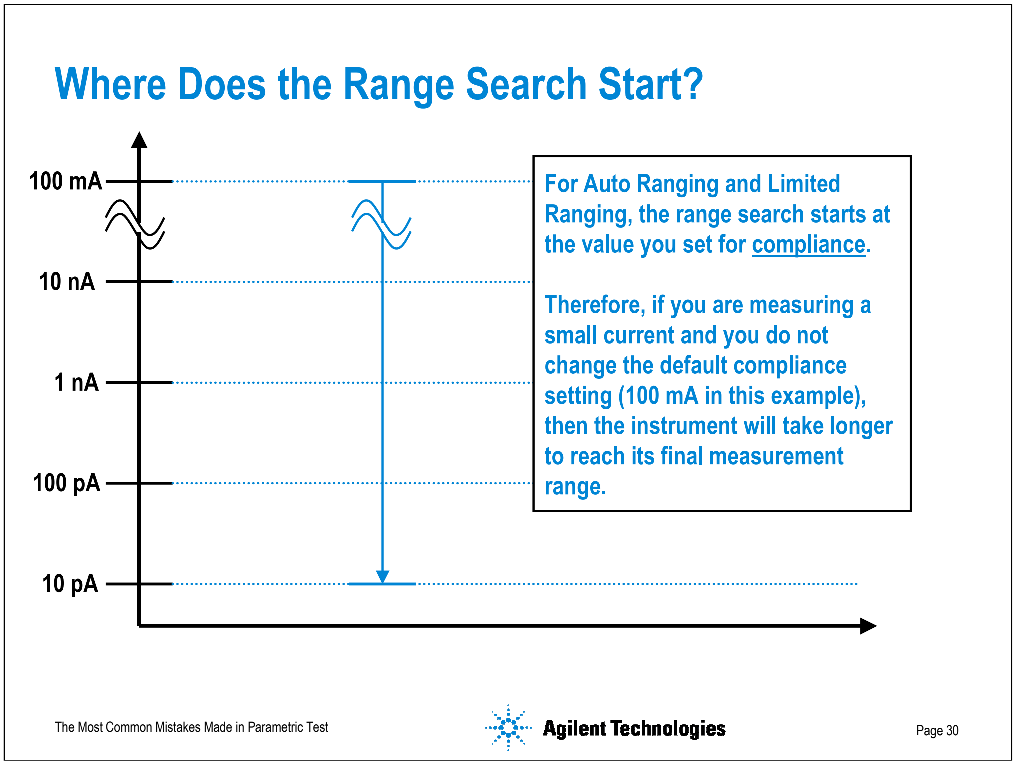
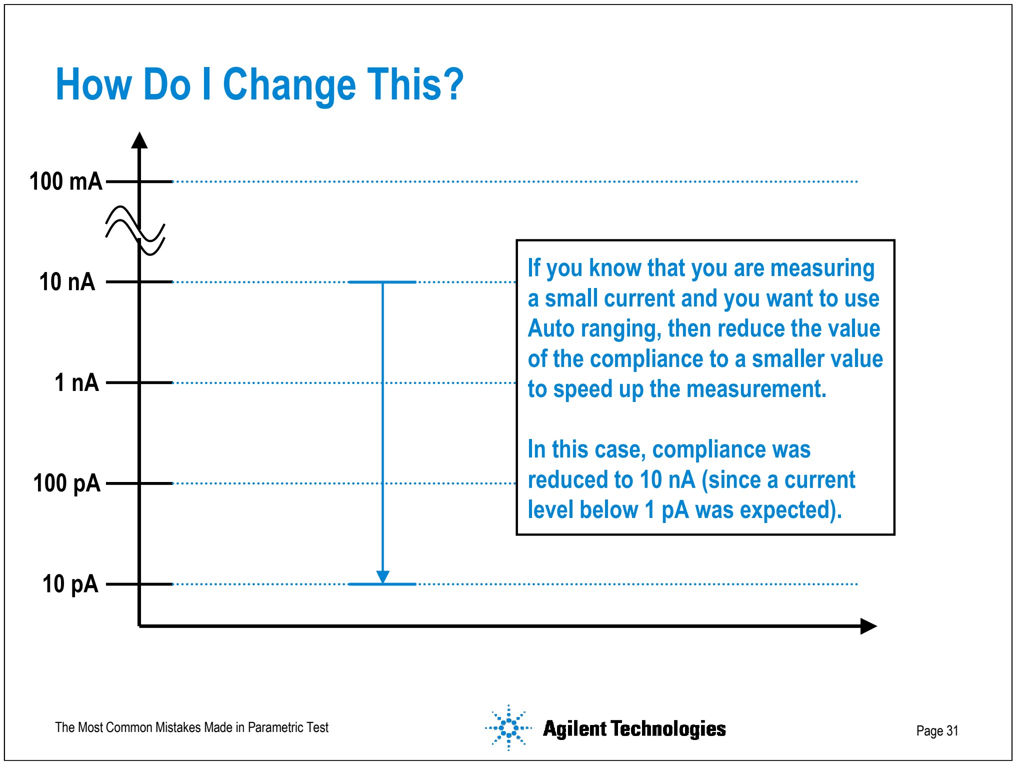
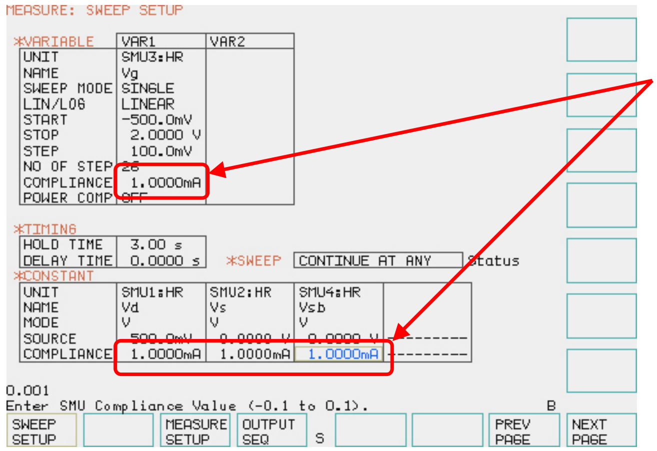


Many people ask the question: Where does the range search start when I use Limited or Auto ranging? The answer is that it starts at the value that you specify for measurement compliance.



Lowering the specified compliance value will change the point from which Limited and Auto ranging will begin their range search.

Changing the 4155/4156 Compliance Settings



Reduce the compliance settings to speed up your low-current measurements

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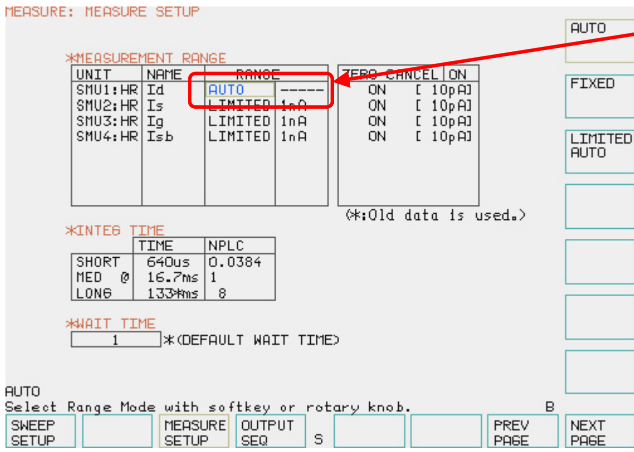
For example, on the 4156C you can change the compliance setting from the “SWEEP SETUP” window. You can also do this under computer control using I/CV automation software.

Remember! Need AUTO Ranging for Low Current



Keep in mind that reducing the compliance speeds up your measurement, but you still need to be using AUTO ranging in order to measure low currents (fA level)

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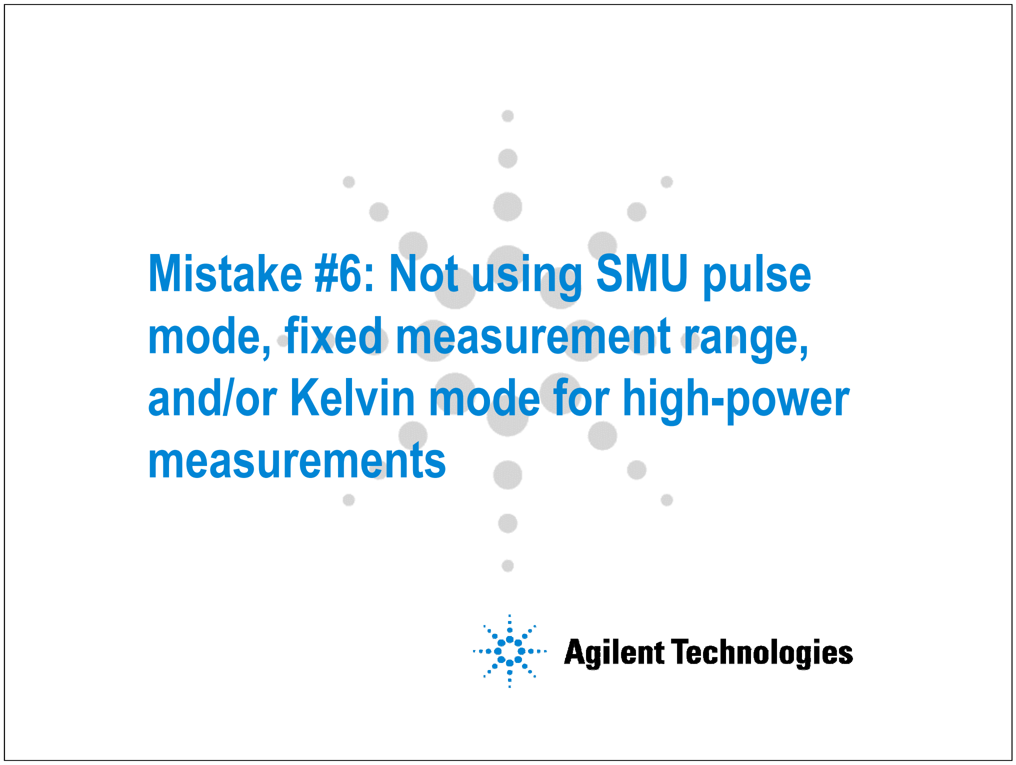
Remember that even if you lower the compliance value, you still need to select “AUTO” ranging in order to measure low currents.


Mistake #6: Not using SMU pulse mode, fixed measurement range, and/or Kelvin mode for high-power measurements
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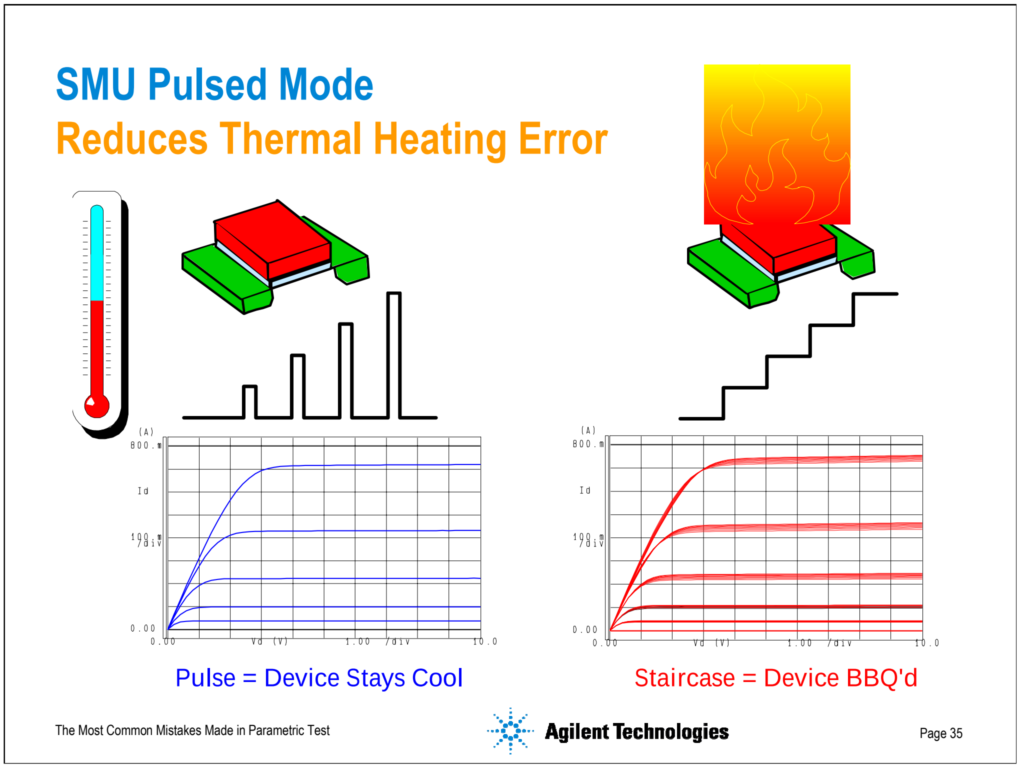
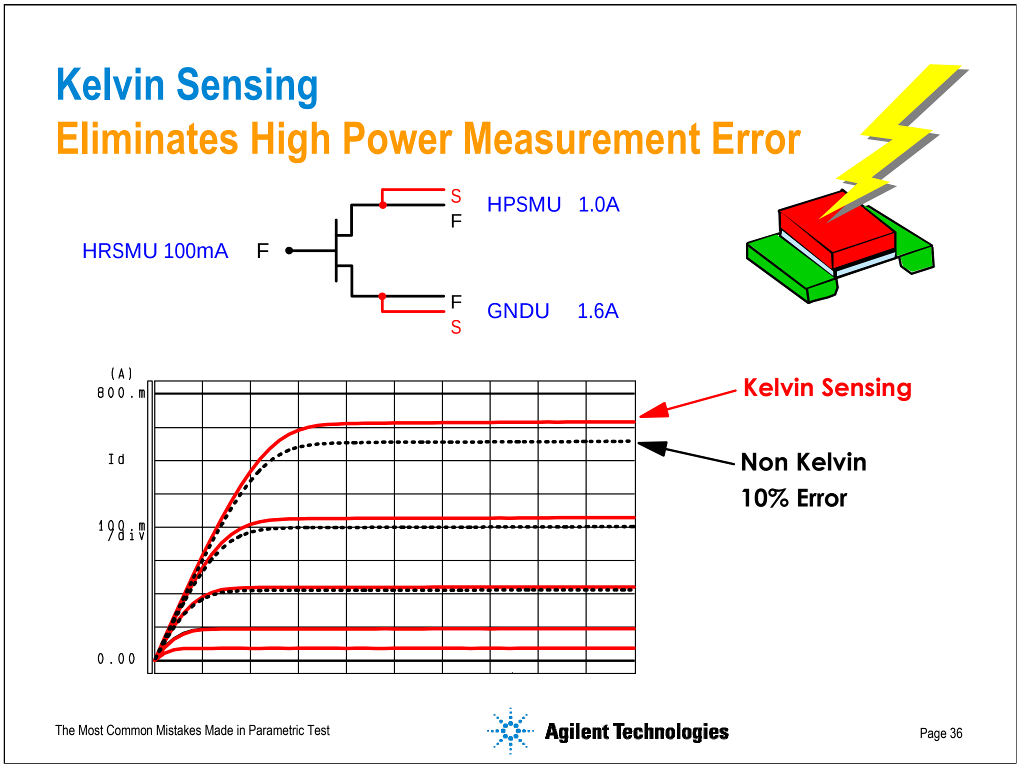


High-power devices require special measurement considerations. This section will address a couple of important measurement considerations for power MOSFETS and Bipolar transistors.

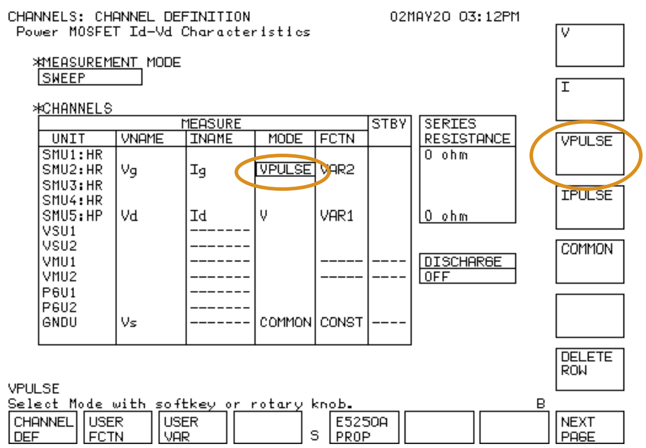
One of the most important techniques for measuring power devices is to reduce the power duty cycle by applying voltage or current pulses during measurement (as opposed to simply applying constant DC voltages or currents).



For high-power devices, it is extremely important to use Kelvin (4-wire) measurement techniques. In this case the measurement error is not coming from any sort of thermal device effect, but rather from the Ohmic drop that occurs in the cables going to the device under test.

Using SMUs in Pulsed Mode

Channel Definition Page



Press the "VPULSE" softkey to define the voltage pulse mode. In this case the gate SMU will be pulsed.

Note: Only ONE SMU can be in pulsed mode.

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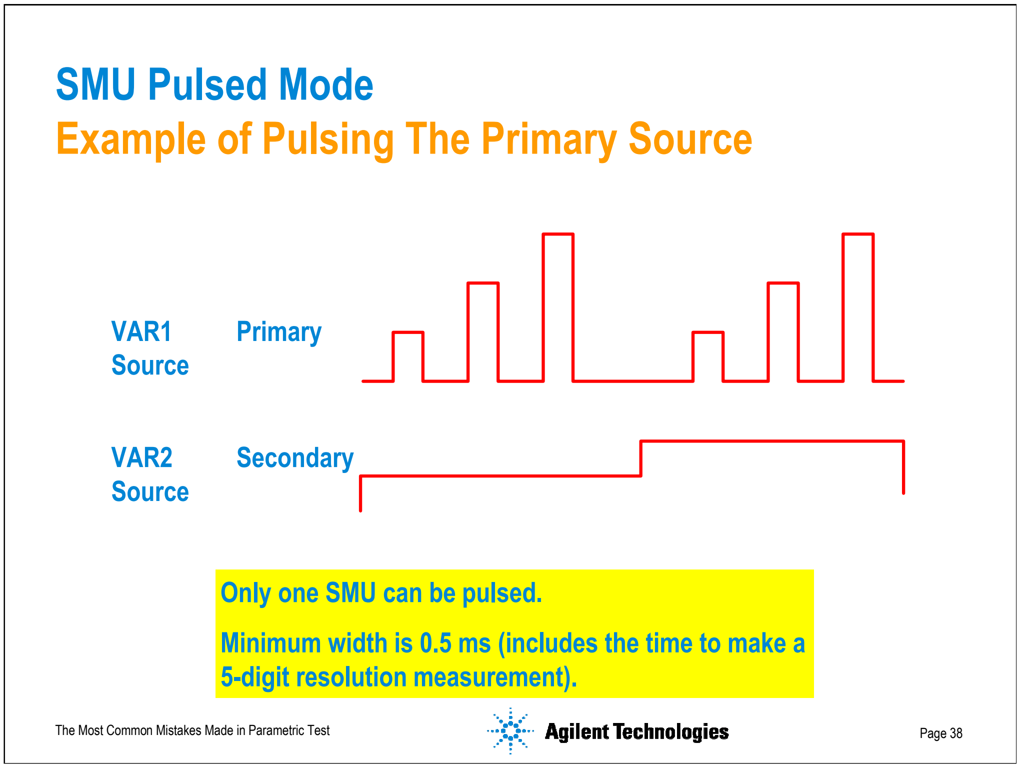
The 4155 and 4156 allow you to define one of their SMUs to be in pulsed mode. You need to do this on the "CHANNEL DEFINITION" page of the instrument front panel. Of course, this feature is supported in Agilent I/CV as well.



For a sweep measurement, you typically want to pulse the swept source (VAR1). The VAR2 source is varied in order to produce a family of curves, and it does not require pulsing. The minimum pulse width is determined by the time that the instrument requires in order to make a 5-digit measurement.

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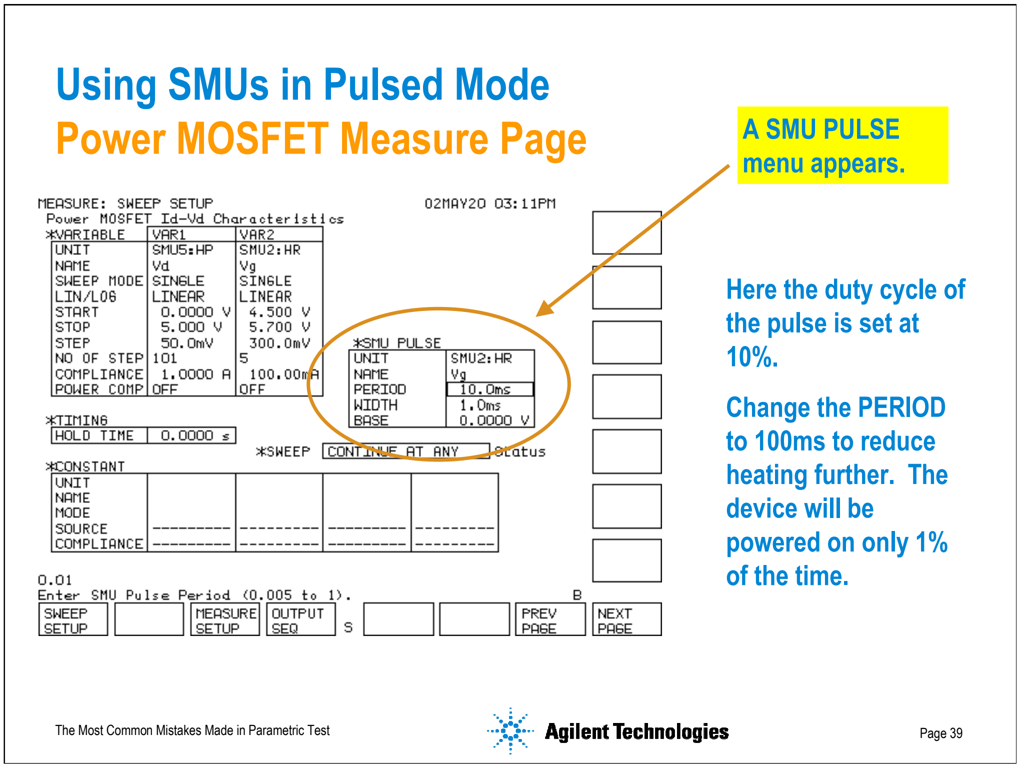
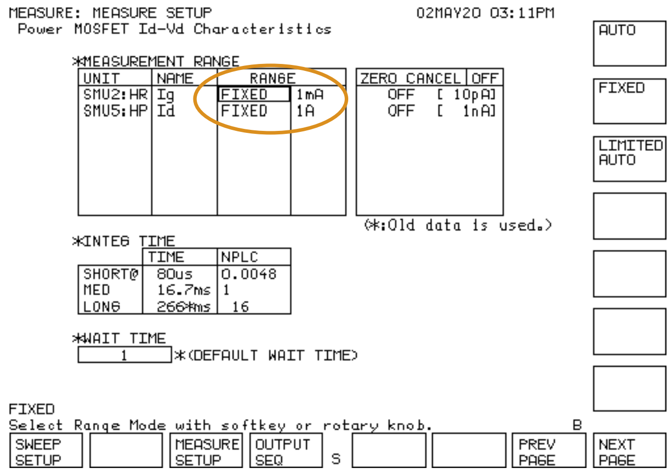


If a pulsed SMU is defined on the “CHANNEL DEFINITIONS” page, then an SMU pulse menu will appear on the “SWEEP SETUP” page of the 4155/4156.

Using SMUs in Pulsed Mode

Measure Setup Page



VERY IMPORTANT!

Use FIXED ranges.

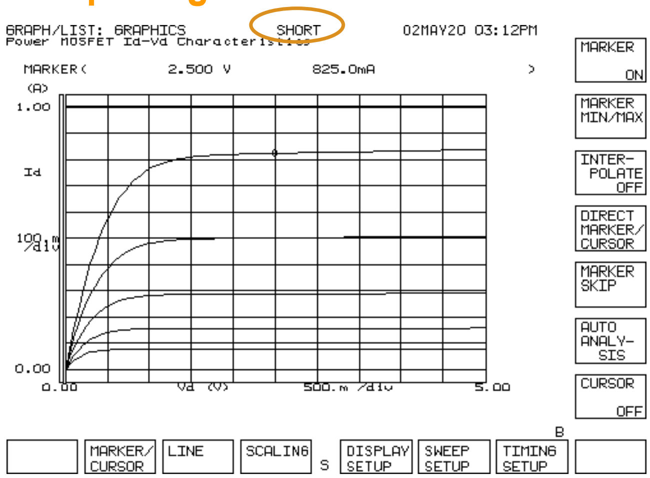
FIXED prevents the SMUs from auto ranging. AUTO over-rides the pulse settings and could add up to 30ms on each range change.

Here Id is set to the 1Amp range to make use of the HPSMU in the expander box.

When making pulsed measurements, it is VERY important to use FIXED measurement ranging. If you use LIMITED or AUTO ranging, then you can easily over-ride your pulse timing setups. This is because the instrument will also choose accuracy over measurement speed when confronted with a conflict between the two.

Using SMUs in Pulsed Mode

Graph Page



VERY IMPORTANT!

Use SHORT integration.

This minimizes heating and assures proper timing.

LONG integration will over-ride your pulse width/length setting. Much more time is required for long integration.

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Besides selecting FIXED ranging, you need to make sure that you are using SHORT integration. The reason is the same: otherwise, accuracy will over-ride your pulse settings.

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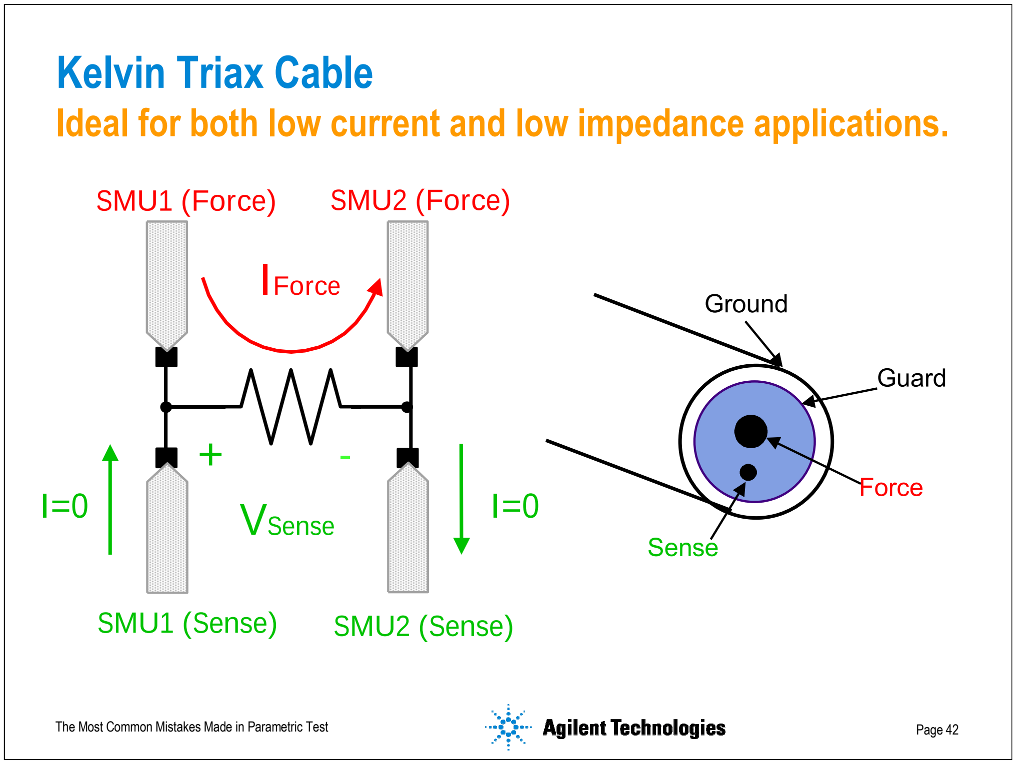

The 4155 uses the same triax cables as the 4142 and 4145. These cables are good for low current measurements. However, two cables are necessary for low resistance Kelvin measurements.

Agilent Technologies designed a special Kelvin triax cable for the 4156, E5260 Series, and E5270B/4157B. This cable is optimized for both low current and low resistance measurement. Both force and sense lines are held rigidly in the same Teflon cable. Friction is reduced and the cable is less sensitive to noise caused by moving the cable.

Kelvin triax cable assemblies are available with two connector options:

16434A	4156 compatible on one end; 4142 compatible on the other end
16493K	4156 / E5260 Series / E5270B compatible on both ends (standard option)

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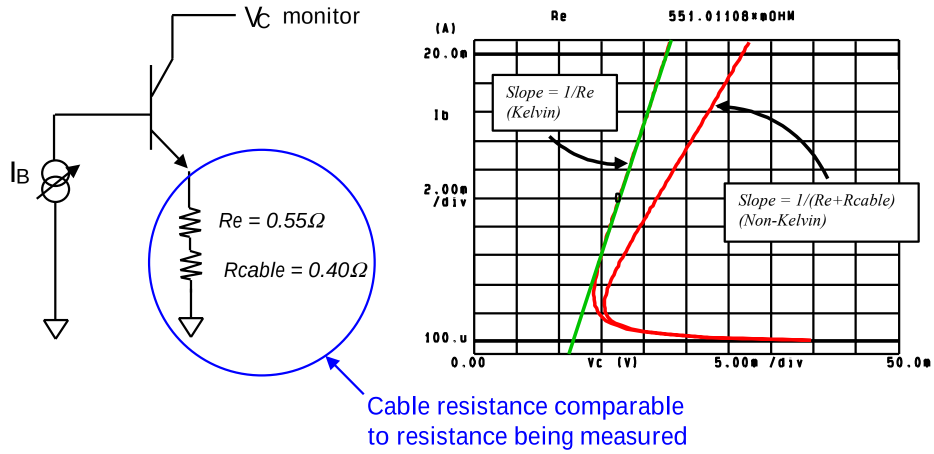
Non-Kelvin Measurements Can Introduce Significant Error



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In the example above, the device is connected with a SMU on the base sweeping current, a voltmeter on the collector, and the emitter is grounded with a Kelvin SMU. The base SMU does not have to be Kelvin since we are only forcing current and do not care about measuring the cable loss in the base. Also, the collector SMU is being used only as a high impedance voltmeter, so there is no cable loss in this lead.

The emitter on the other hand, must be connected to a Kelvin SMU. Because of this, we can compensate for the 0.40 ohm path through the cable and fixture. From the graph we can see the emitter resistance is 0.55 ohm when compensated using the Kelvin connection. Non-Kelvin resistance is 0.95 ohm, due to the extra 0.40 ohm cable and fixture resistance error.

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Wafer Prober Kelvin Cable Connections
Optimized For Measurement Accuracy

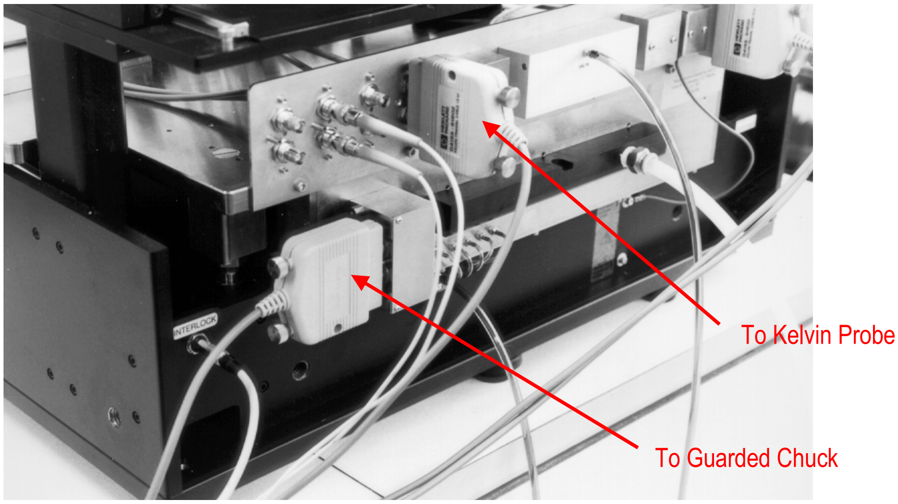

Photo of SMU cable connection to a Cascade Microtech Summit probe station.

Kelvin triaxial cables mate directly to up to six probes top side and a guarded Kelvin chuck (substrate) connection. There is even a provision for mating to the Agilent GNDU configuration

This station uses the Micro Chamber (TM) design for a small volume shielded box enclosing only the probes and wafer; not the entire probe station. The rigid mechanical design with guarded chuck provides an ideal environment for fA current, fF capacitance, and µV voltage measurements.

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Mistake #7: Using 'Auto' ranging in Time Sampling Mode (4155/4156)

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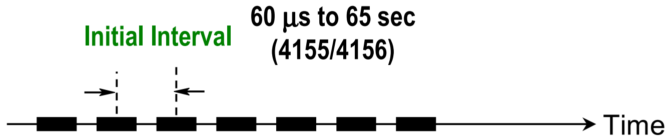
What is Time Sampling?



Time sampling involves measuring a voltage or current at regular intervals over time.

Useful for certain types of reliability stress measurements such as Time Dependent Dielectric Breakdown (TDDB)

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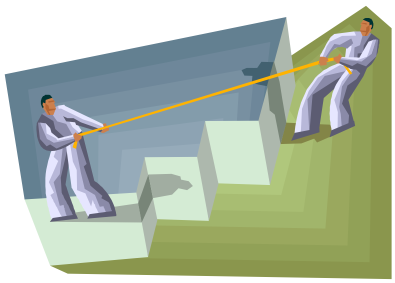
Time sampling is one of three available measurement modes on the 4155/4156. The other two are Sweep and Stress.

Specifying a Small Sampling Interval and Auto Ranging Creates a Conflict!



- Time sampling inherently requires that the measurement occur within a certain time period. Otherwise, the sampling rate cannot be met.
- Auto ranging requires the instrument to start at the specified compliance value and work its way down to the correct measurement range, which takes time.
- Specifying both a short sampling time (fast sample rate) and auto ranging creates a conflict for the instrument!

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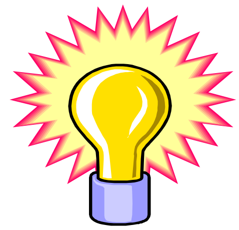
Remember! Whenever Agilent instruments are confronted with a conflict between measurement speed and measurement accuracy, accuracy will always win-out.

How Does this Conflict Get Resolved?

- **Accuracy always wins out over speed**
- **The instrument will take as long as necessary to auto range, ignoring the specified measurement interval settings**
- **The end result is that the instrument will not measure at the interval you specified!**



NEVER USE AUTO-RANGING WHEN MAKING FAST TIME SAMPLING MEASUREMENTS

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Many times people call in with support questions as to why they are not getting the time sampling rate that they specified. In virtually every case, we find that they are using AUTO ranging, which creates a conflict when specifying fast sampling rates.

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How Do I Optimize My Time Sampling Measurements?

Besides using FIXED ranging, what else do I need to do to optimize my Time Sampling measurements?

- Minimize active units
- Measure on only one resource
- Disable the STOP condition
- Minimize the compliance setting

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There are several other requirements to obtain the sampling rate that you specify (in addition to using FIXED measurement ranging). ALL of these conditions must be met. For more information, please refer to the 4155/4156 data sheet.

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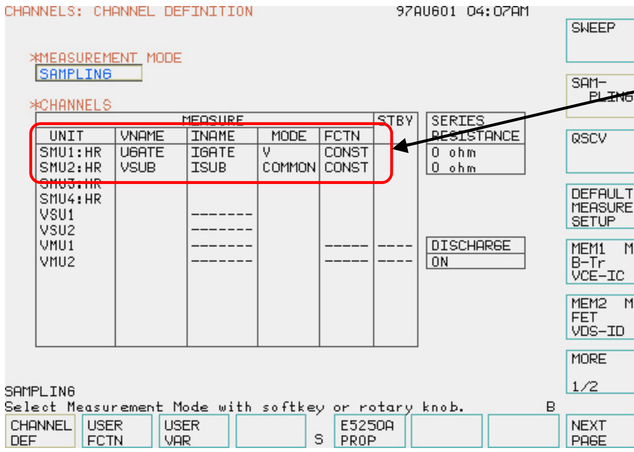
Optimizing Time Sampling Measurements - 1



Minimize the number of active resources to only those that you need.

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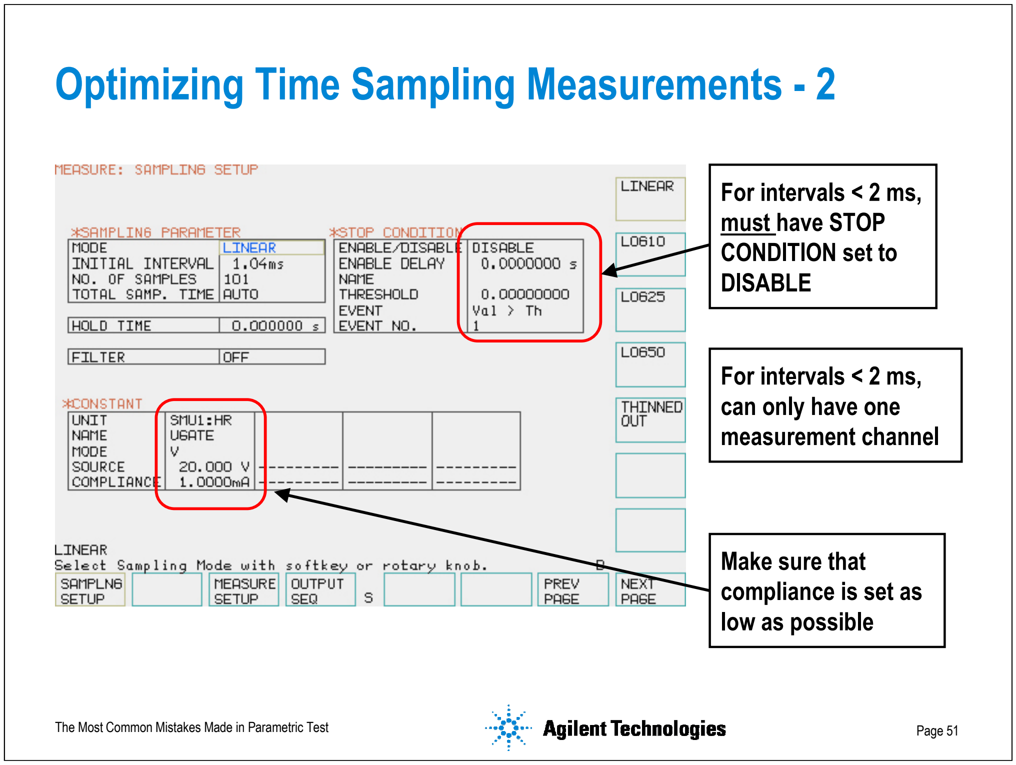
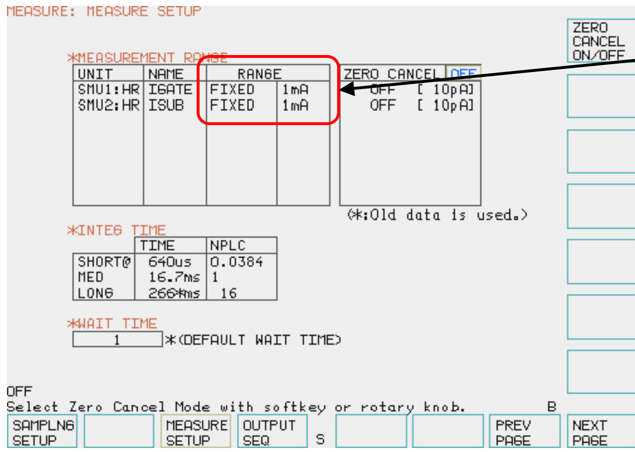
It is a good idea to minimize the number of measurement resources that you have active in the "CHANNEL DEFINITION" page.



Another very important condition is that you only have one measurement channel defined. Specifying more than one measurement channel is not allowed for time intervals less than 2 ms.

Also, for time intervals less than 2 ms you must have the “STOP CONDITION” set to “DISABLE”.

Optimizing Time Sampling Measurements - 3



For intervals < 2 ms, <u>must</u> used FIXED measurement range (never use AUTO ranging).

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As previously mentioned, you MUST use FIXED measurement ranging for measurement intervals less than 2 ms.

Mistake #8: Improperly connecting SMUs in parallel

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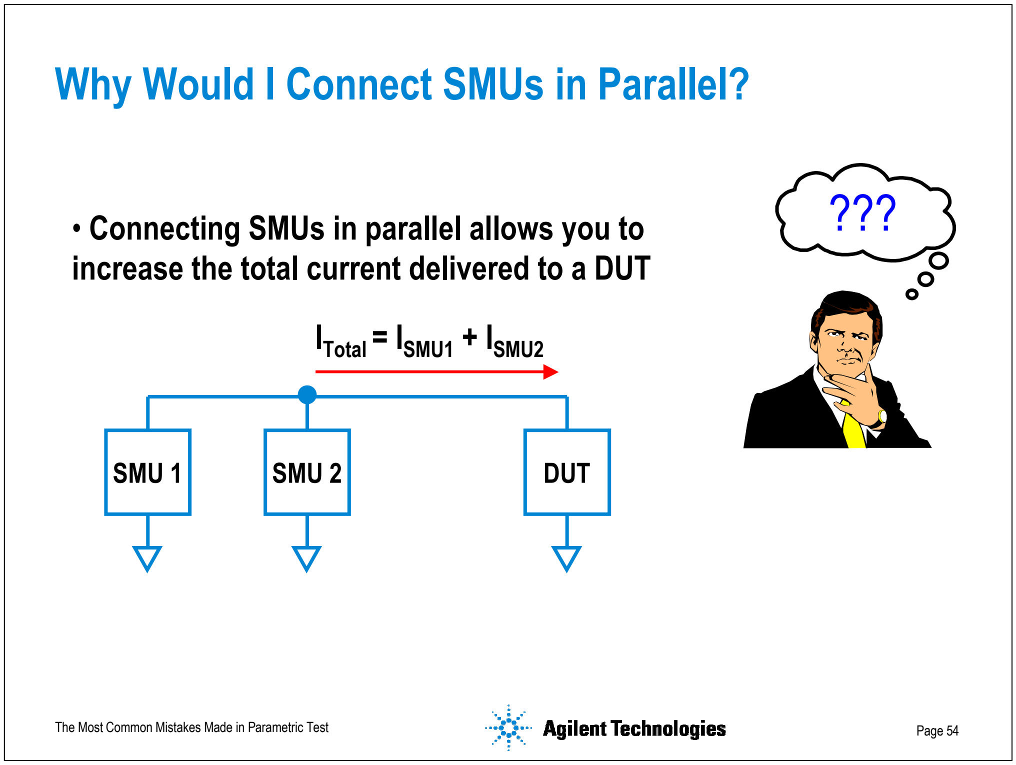
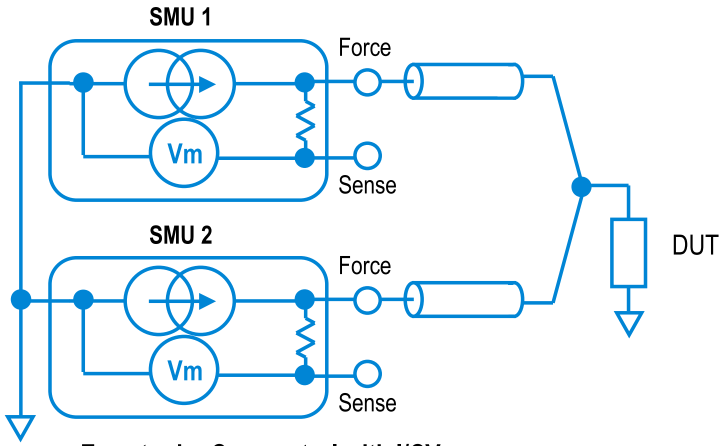


Connecting SMUs in parallel has many practical benefits. However, the actual implementation must be done carefully due to practical limitations of the SMUs.

I Force, V Measure (Non-Kelvin Connection)



- **Easy to do: Can control with I/CV**
- **Voltage measurement accuracy is relatively poor**

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This shows a simple case where the two SMUs are both in current force mode (non-Kelvin connection).

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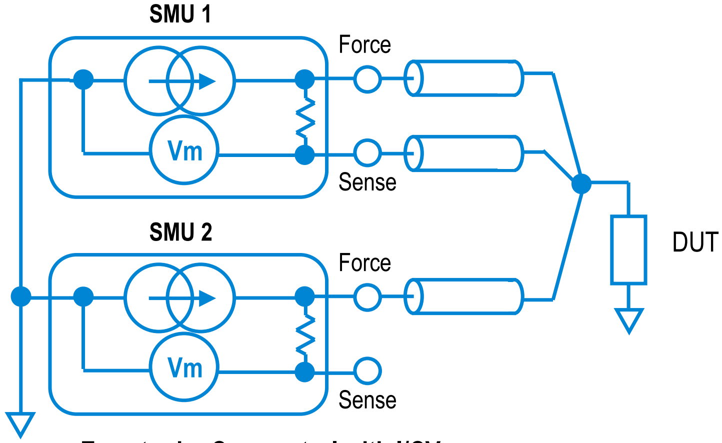
I Force, V Measure (Kelvin Connection)



- Easy to do: Can control with I/CV
- High voltage measurement accuracy

This shows a slightly more complicated case where both SMUs are in current force mode, but one SMU is connected in a Kelvin configuration to improve the voltage measurement accuracy.

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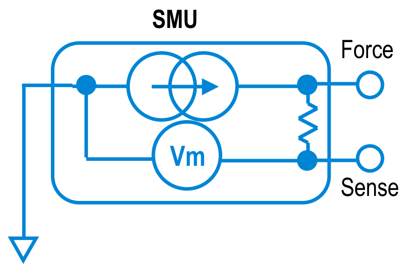
Current Force Mode is not Always Useful



Paralleling SMUs in current source mode is easy, BUT:

- **Not all applications can be covered this way**
- **It begs the question of how to parallel SMUs in voltage force mode**

Connecting SMUs in parallel in current force mode is relatively trivial. However, the usefulness of this procedure is limited. Most of the time we want to force a voltage, and we want to place SMUs in parallel in order to improve the the current sourcing capability of our voltage source.

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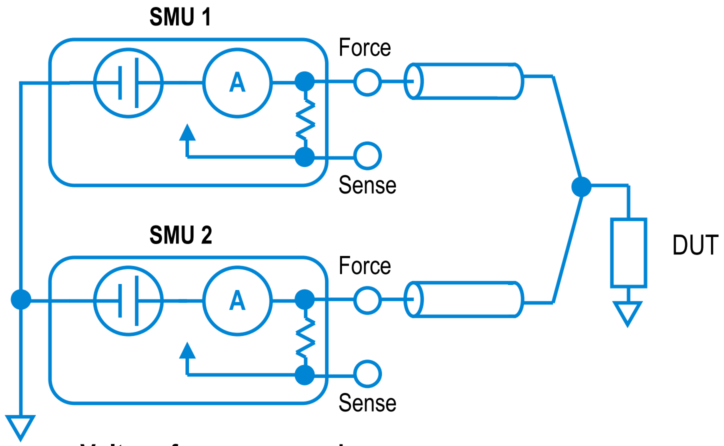
V Force, I Measure (Non-Kelvin Connection)



- **Voltage force accuracy is poor**
- **Easy to use in concept, BUT requires great care to prevent two voltage sources from interfering with one another**

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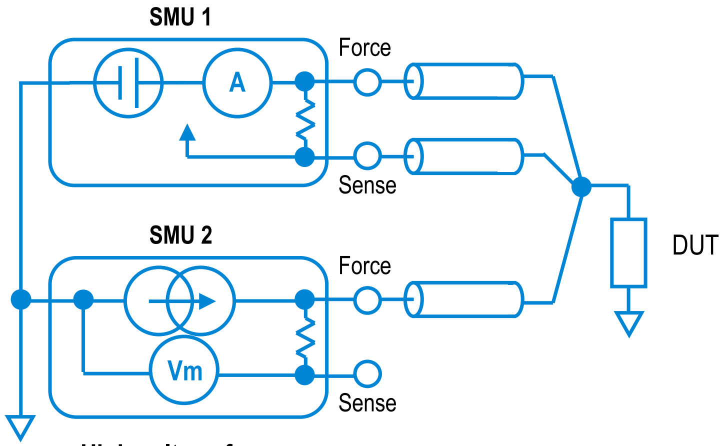
This is the simplest case of paralleling two SMUs in voltage force mode. Since this is a non-Kelvin connection, the current measurement accuracy is rather poor. In addition, as we shall see this configuration is quite tricky if we want to keep the two SMUs from conflicting with one another.

V Force, I Measure (Kelvin Connection)



- **High voltage force accuracy**
- **Requires sophisticated measurement control software**

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In this situation, one SMU is forcing voltage and measuring current, while the other is acting as a current source. This configuration can work well, but it has some limitations as is shown in the next slide.

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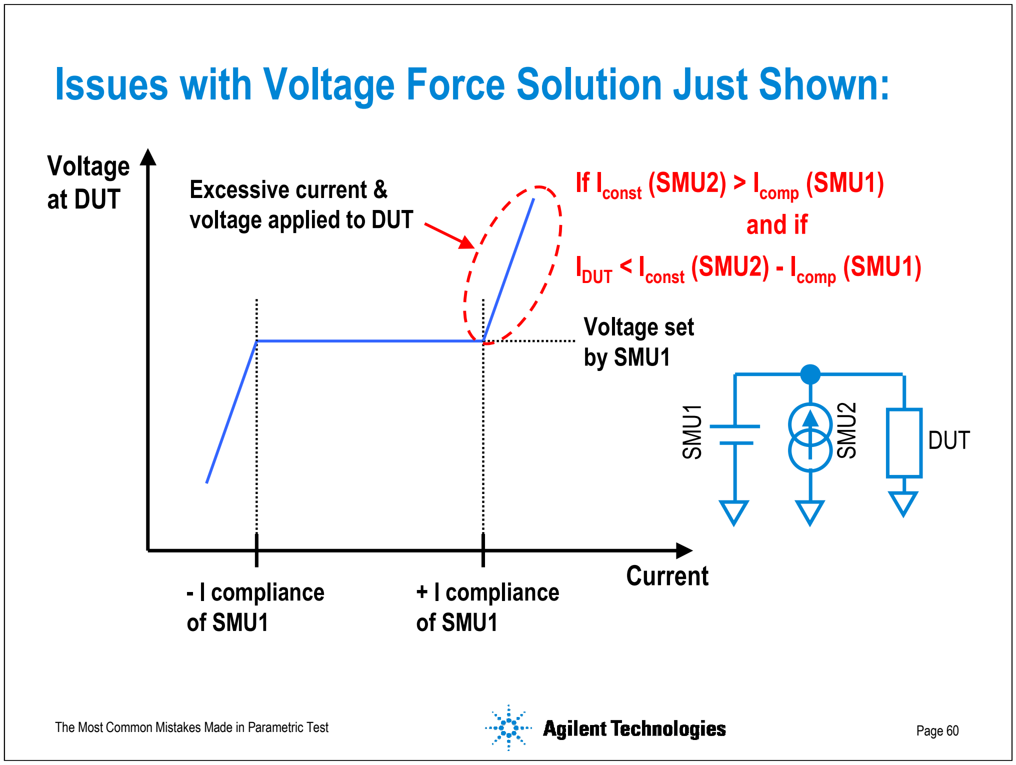
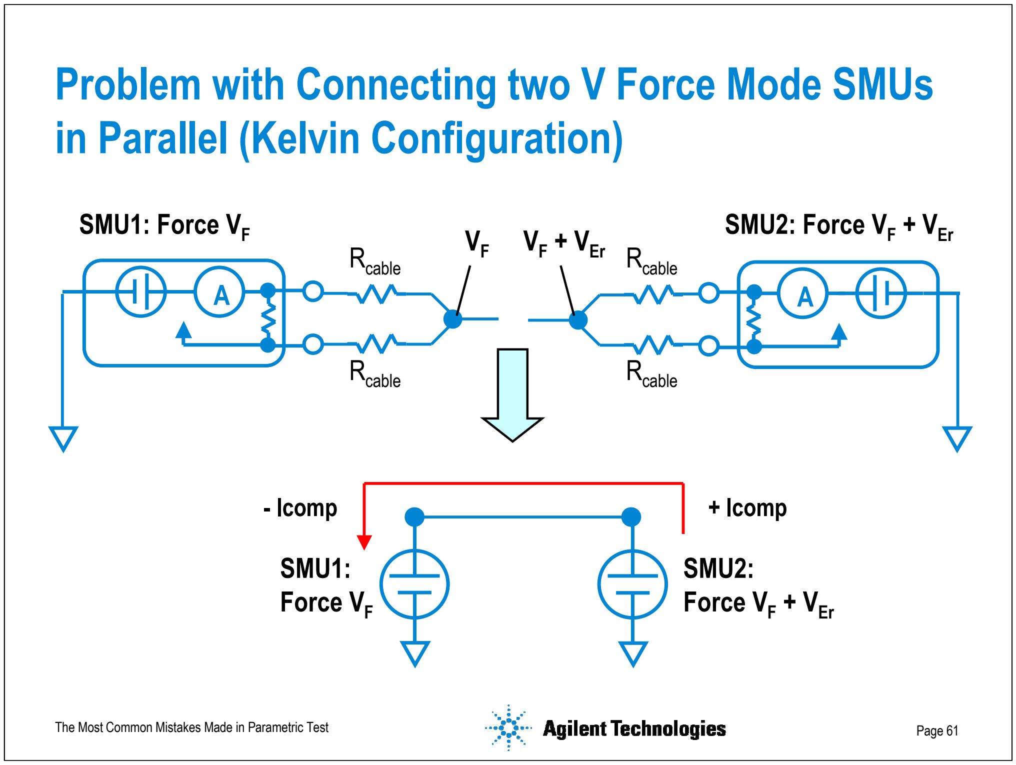
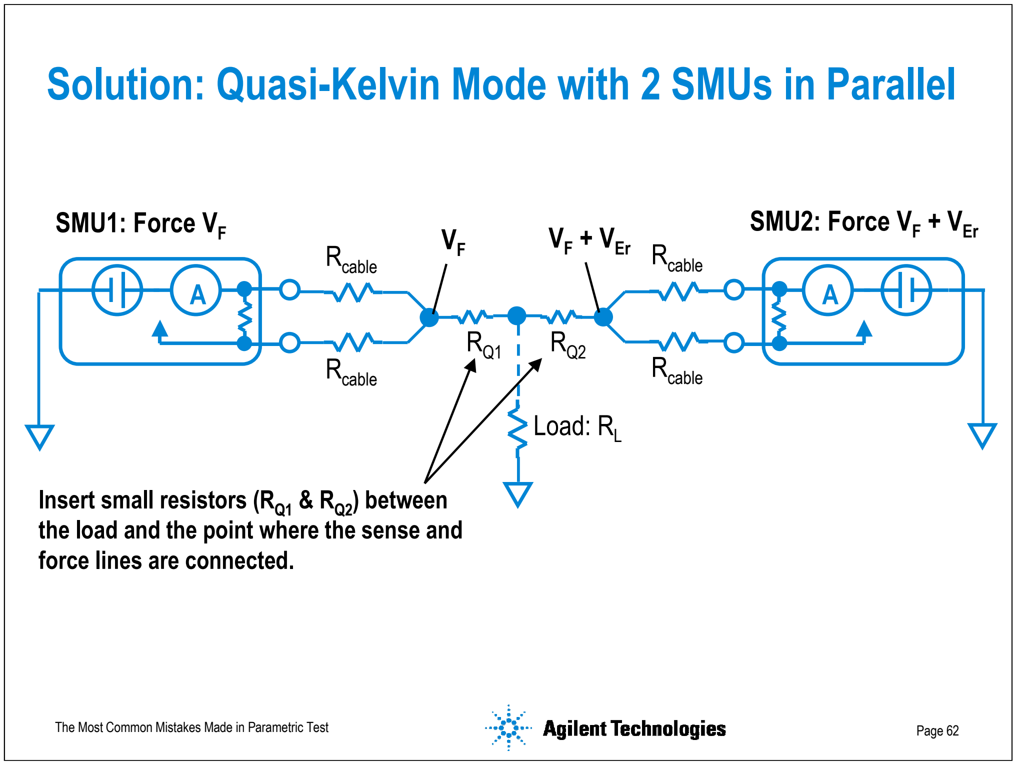


For the case shown in the previous slide, if the measured current deviates from the +/- I compliance range of the SMU in voltage force mode, then erroneous measurement results will be obtained.

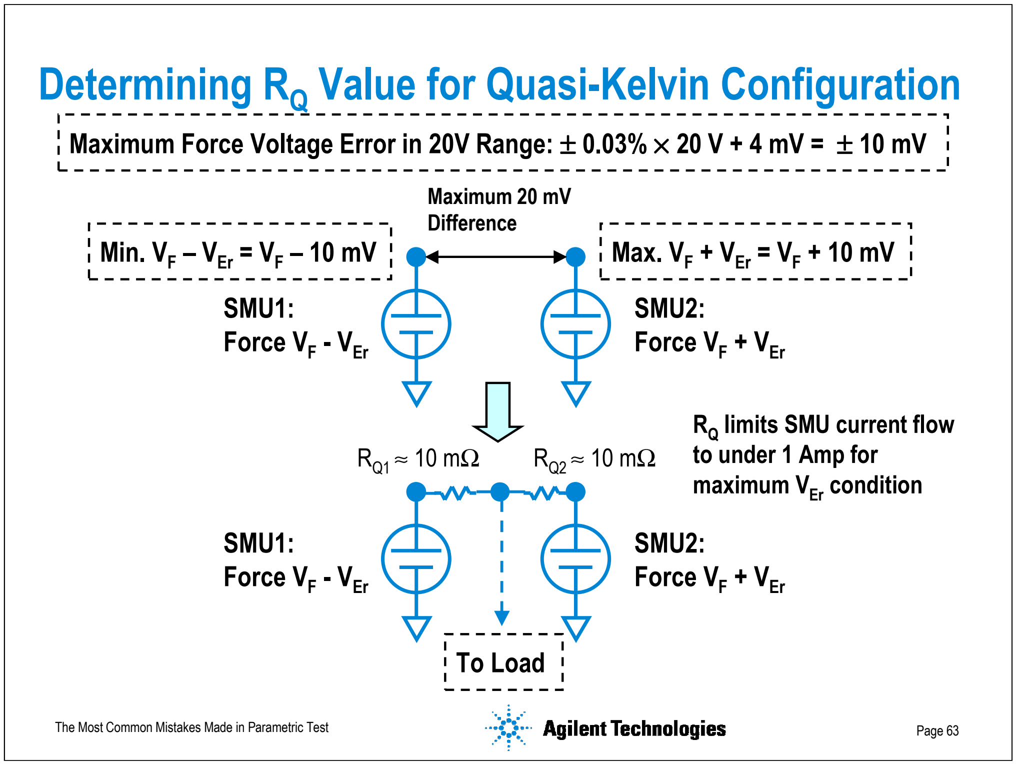


Let us examine the case of placing two SMUs in parallel in voltage force mode with a Kelvin configuration.

The problem with this approach is that, even if you specify the exact same voltage for both SMUs, in practice there will be some voltage force error between the SMUs. This will cause one SMU to source current into the other SMU and very quickly one or both SMUs will hit their current compliance limit.

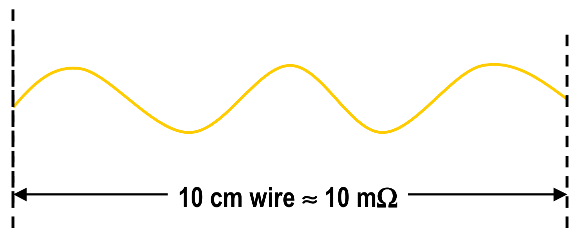


To prevent the situation shown on the previous slide, we create a “quasi-Kelvin” configuration using two small resistors. These resistors limit the current flow to keep the SMUs from hitting compliance.



This slide calculates the values of the resistors required in order to limit the current flow from one SMU to another.

How Do I Create a 10 mΩ Resistance?



A 10 cm wire has an equivalent resistance of about 10 mΩ, so this is usually the simplest means to insert this resistance.

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Mistake #9: Failure to account for electro-motive force (EMF) on sensitive voltage measurements

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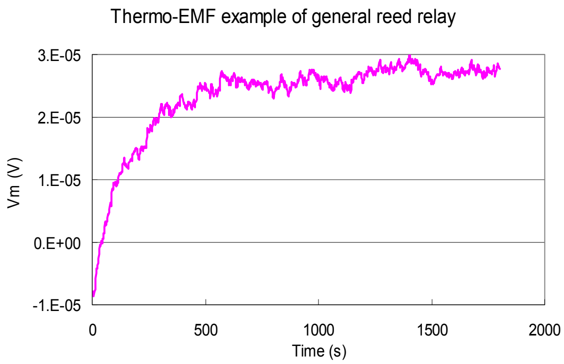
Thermo Electro-Motive Force (EMF): What is It?

- **A transient voltage pulse that is associated with reed relay switches.**



Note: This is NOT an example of the relays used in our instrumentation.

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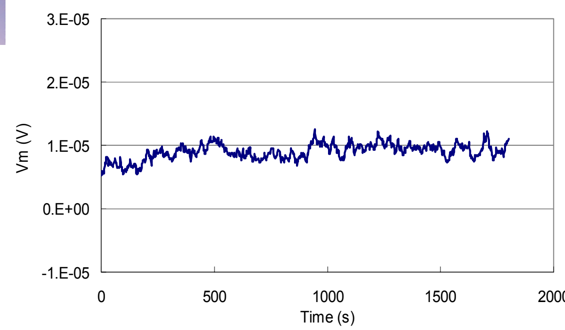
Conventional reed relay switches, which can be obtained from a variety of sources, typically generate a thermo-EMF (electro-motive-force) ranging from a few tens of micro-volts to a few hundreds of micro-volts after the relay activation current is turned on or off. This voltage drift, which can continue for several minutes before dying out, is usually not acceptable when making precision measurements such as those required for BJT matching characterization. The above figure shows an example of the thermal-EMF generated by a commercially available reed relay.

Agilent 4073A/B Relays Eliminate Thermo-EMF

Agilent 4073A example through the switching matrix



The Agilent 4073A and 4073B test systems use a proprietary reed relay that almost completely eliminates the thermo-EMF problem. The above graph illustrates the dramatic difference between the performance of the 4073A/B relays versus those shown on the previous slide. As you can see, the relays in the 4073A/B act as near ideal switches.

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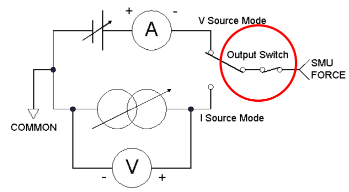
Managing the Use of a Reed Relay Switch

- **Wait until the thermo-EMF has stabilized to its final value.**
  - **For the 4156C and E5270, set the SMU output relay to its on (closed) state after warm-up and keep it there.**



- **Complete the measurement as quickly as possible.**
  - **Complete the measurement within 10 seconds. This keeps the total drift to less than a few micro-volts.**

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The reed relays used in semiconductor parameter analyzers and switching matrices are not as close to the ideal case as are those used in the 4073A/B. The data sheet specifications of the parameter analyzer SMUs take the thermo-EMF effects into account so users do not have to worry about this effect for normal applications. However, when performing measurement for matching applications that require extremely high levels of accuracy beyond the normal specifications, the guidelines shown above can minimize or eliminate the thermo-EMF effects.

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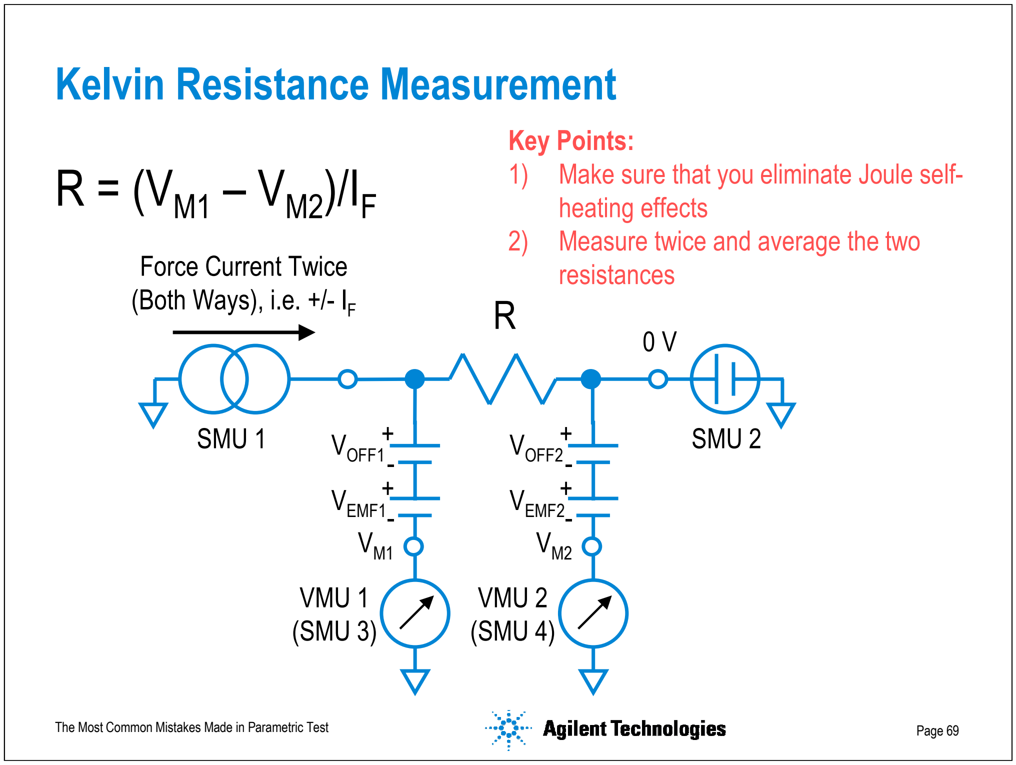

A resistor can be measured accurately in two ways: using the Kelvin (or 4-terminal) measurement method with a precision resistance meter, or using SMUs and VMUs as shown in the above figure. To obtain a successful resistance measurement, two things are important: 1) elimination of the Joule self-heating effect, which will increase the temperature of the device, and 2) measuring twice, which requires applying current in both directions by switching the polarity of the force current (I_F). By measuring twice, you can take the average of the two resistances to cancel the offset voltage of the VMU (or voltage sense) and the thermo-EMF of the connection terminal. The easiest way to measure resistors is by using the SMU/VMU method, because the current (effectively the power) applied to the resistor can be controlled.

In the case of the E5270B/4157B, the MPSMU and HRSMU both have a voltage measurement resolution of 0.5 μV, which is almost as good as the voltage measurement resolution of the 4155C/4156C VMUs (which is 0.2 μV).

Note: It is left as an exercise for the reader to convince yourself that by applying Kirchoff's current law and voltage law to the above circuit for the two different cases involving the force current and then averaging the two calculated R values, the effects of the thermo-EMF and voltage offset are eliminated.

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VBScript for Kelvin Resistance Measurement

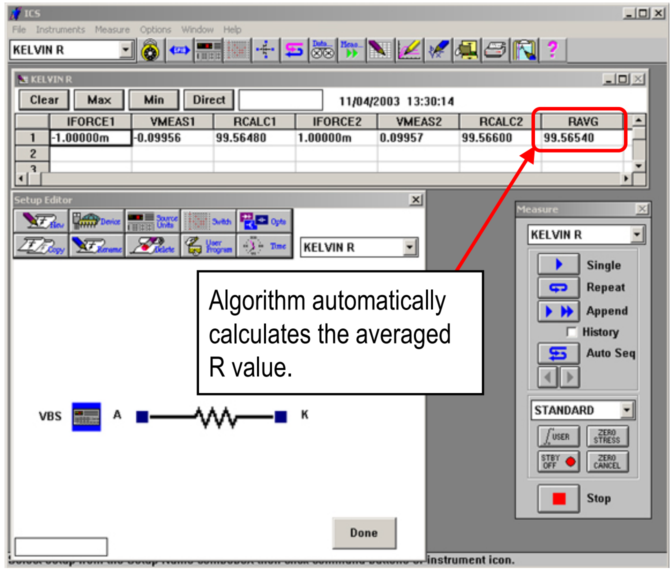
Kelvin_R.vbs - WordPad

```
' Kelvin Resistance Measurement Using VMUs:
' Must use Agilent FLEX Programming Mode:
call MTUtils.CommWrite (linklabel, "US "&Chr(13)&Chr(10), 10)
' ASCII w/header <,>:
call MTUtils.CommWrite (linklabel, "FMT 5"&Chr(13)&Chr(10), 10)
' Spot measurement:
call MTUtils.CommWrite (linklabel, "MM 1,23"&Chr(13)&Chr(10), 10)
' Set auto-calibration mode to OFF:
call MTUtils.CommWrite (linklabel, "CM 0"&Chr(13)&Chr(10), 10)
' Set Integration Time to Long:
call MTUtils.CommWrite (linklabel, "SLI 3"&Chr(13)&Chr(10), 10)
call MTUtils.CommWrite (linklabel, "SIT 3,10"&Chr(13)&Chr(10), 10)
' Set the VMU mode to differential:
call MTUtils.CommWrite (linklabel, "VM 23,2"&Chr(13)&Chr(10), 10)
' Connect the pins:
call MTUtils.CommWrite (linklabel, "CN "&hiterm & "," &lowterm & ",23,24"&Chr(13)&Chr(10), 10)
' Wait for the Thermo-EMF to settle:
call MTUtils.CommWait ((emfdelay*1000)&Chr(13)&Chr(10))
' Set up voltage measurement conditions:
call MTUtils.CommWrite (linklabel, "RV 23,10,2" &Chr(13)&Chr(10), 10)
' Perform Measurement Twice Using Iforce +/-:
For i = 0 to 1 Step 1
  ' Set up the dc current/voltage sources:
  call MTUtils.CommWrite (linklabel, "DI "&hiterm & "," &ri & "," & ifArray(i) & ",2" &Chr(13)&Chr(10), 10)
  call MTUtils.CommWrite (linklabel, "DV "&lowterm & "," &rv &",0,0.1" &Chr(13)&Chr(10), 10)
  ' Wait for circuit to stabilize:
  call MTUtils.CommWait (1000&Chr(13)&Chr(10))
  ' Execute the measurement:
  call MTUtils.CommWrite (linklabel, "XE" &Chr(13)&Chr(10), 10)
  ' Check if operation is complete:
  call MTUtils.CommWrite (linklabel, "*OPC?" &Chr(13)&Chr(10), 10)
  call MTUtils.CommRead (linklabel, B_str, 100, 10)
  ' Check if error(s) occurred:
  call MTUtils.CommWrite (linklabel, "ERR? " &Chr(13)&Chr(10), 10)
  call MTUtils.CommRead (linklabel, A_str, 100, 10)
  'Get the first error message:
  A_str_lth = Len(A_str)
```

For Help, press F1

To obtain the fine control over the instrument measurement resources necessary to make accurate matching measurements when using ICS or I/CV, it is usually preferable to create a Visual Basic Script (VBScript) algorithm. The VBScript option gives the ability to precisely control all of the instrument measurement resources. A sample script is shown above (many such sample algorithms are available from Agilent).

VBScript Measurement Results



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This page shows the measurement results for a ~ 100 Ohm resistor measured using the previously shown algorithm. Data for both the (+) and (-) Iforce cases is shown. Of course, the algorithm could be modified to only return the averaged value.

Mistake #10: Improper Capacitance Measurement Techniques When Using a Switching Matrix

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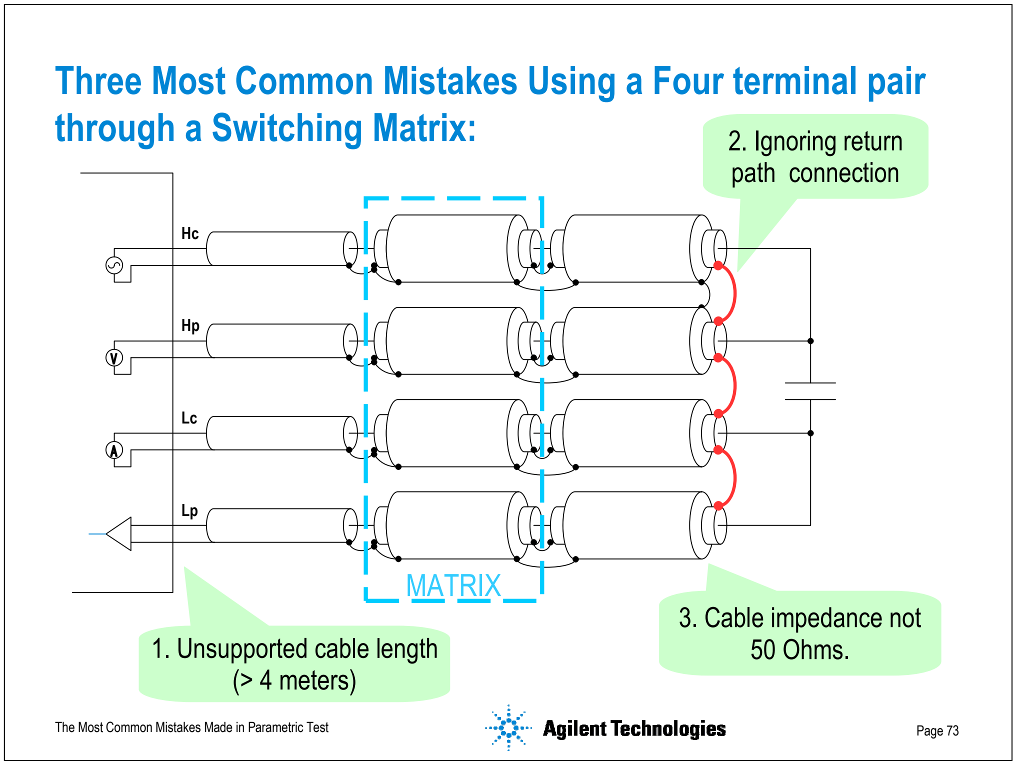
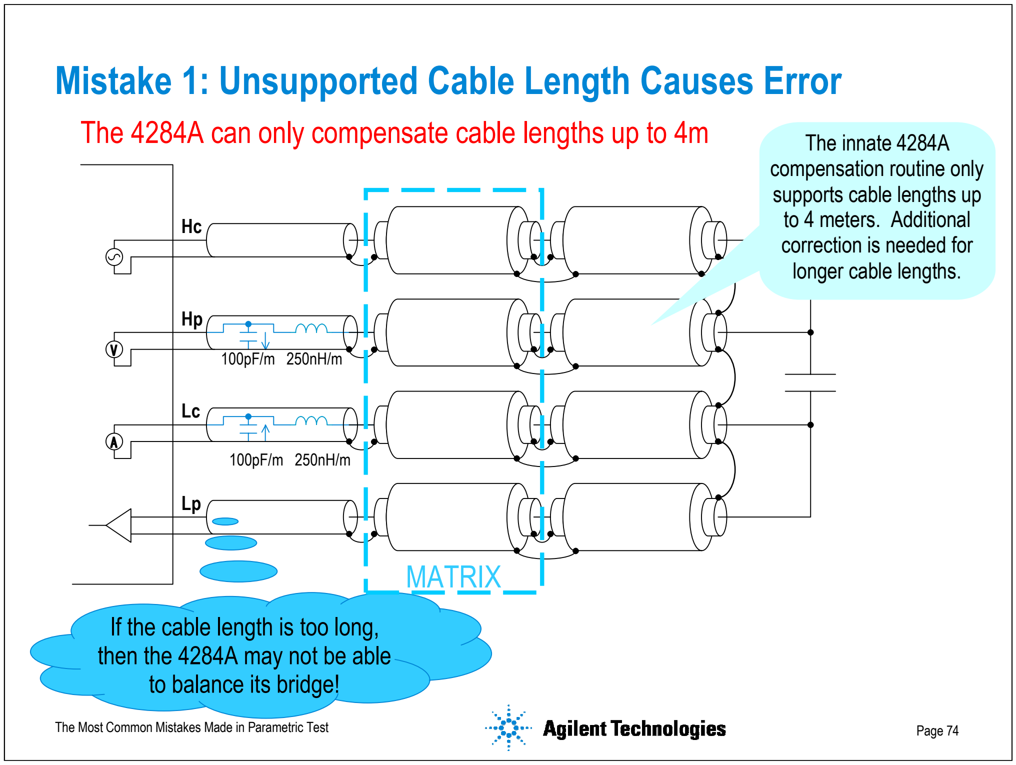
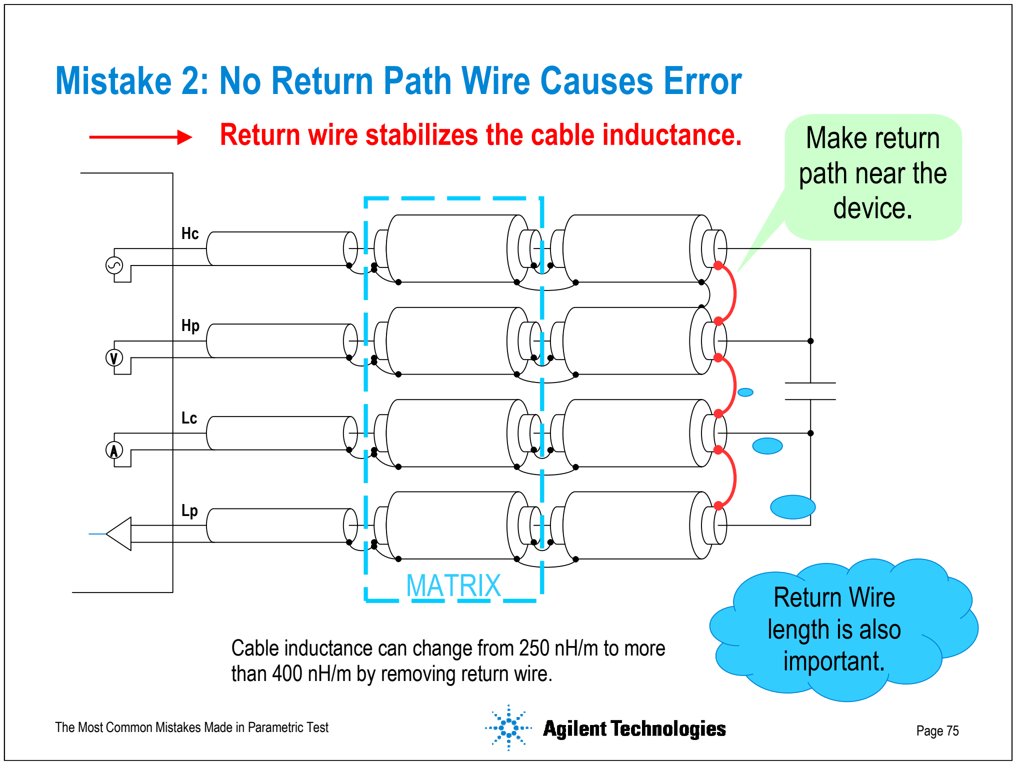


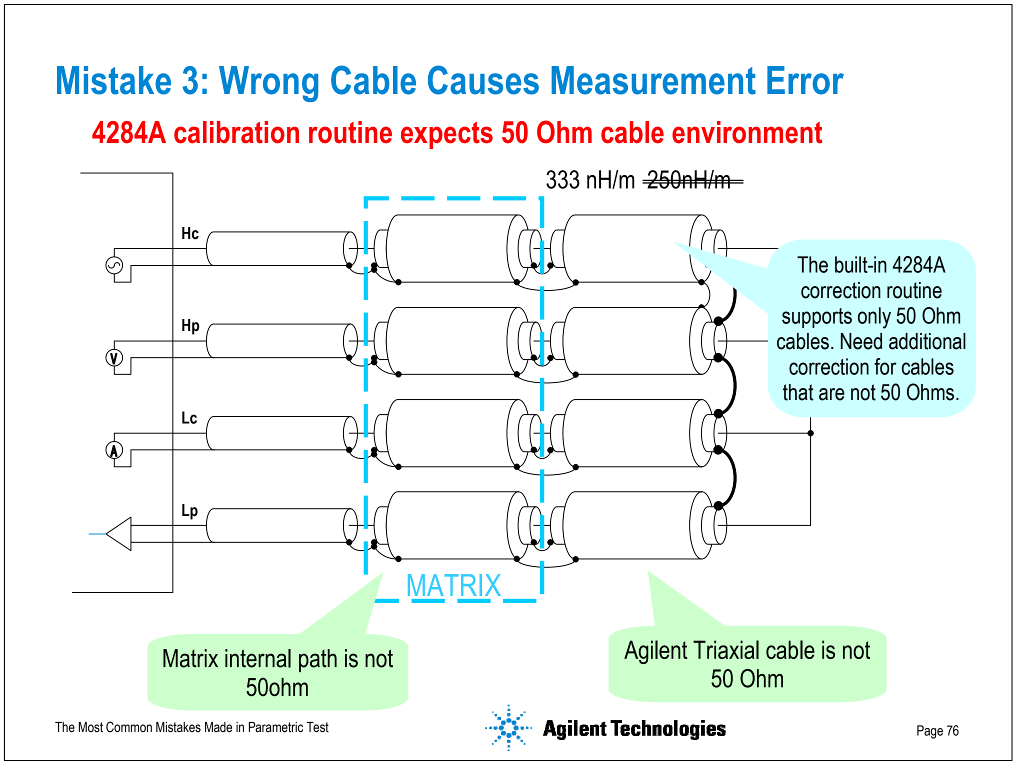
Many users make one or more of these mistakes when connecting up a capacitance meter through a switching matrix. We will look at each of these in-turn.



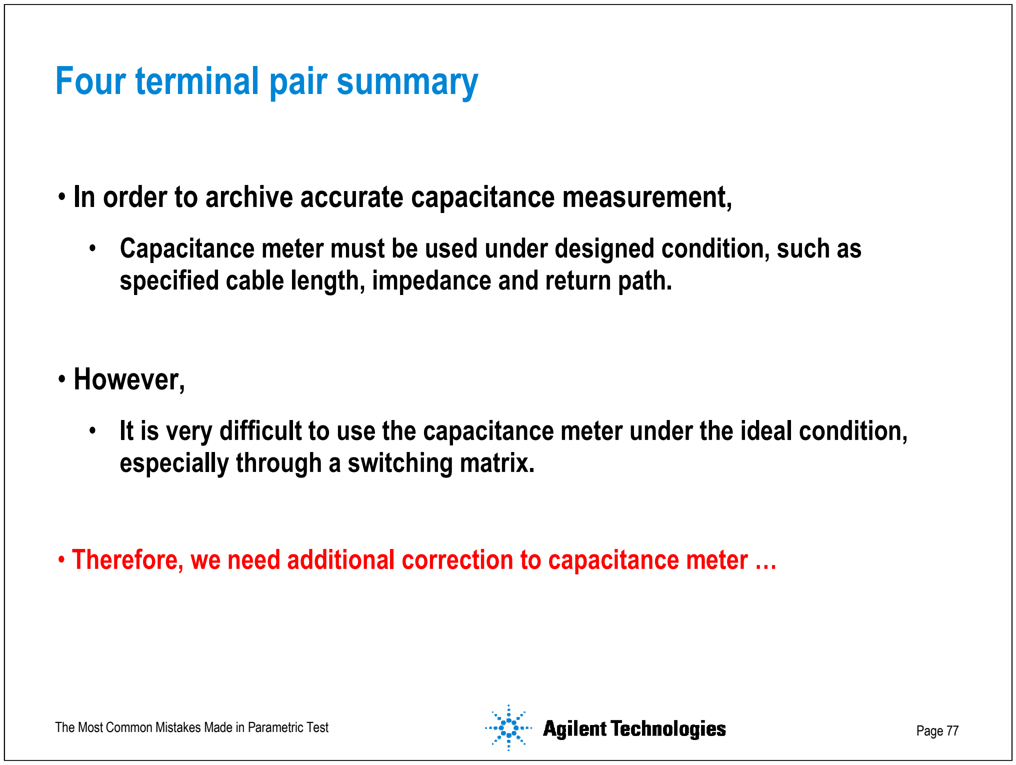
As will be shown, proper cable length is critical for the bridge of the capacitance meter's measurement circuitry to balance.



The outer shield of the BNC cables coming from a capacitance meter are actually NOT at ground potential, but are "virtual grounds". In order to stabilize the inductance of the cables, it is important to supply a "return path" through the BNC shield.

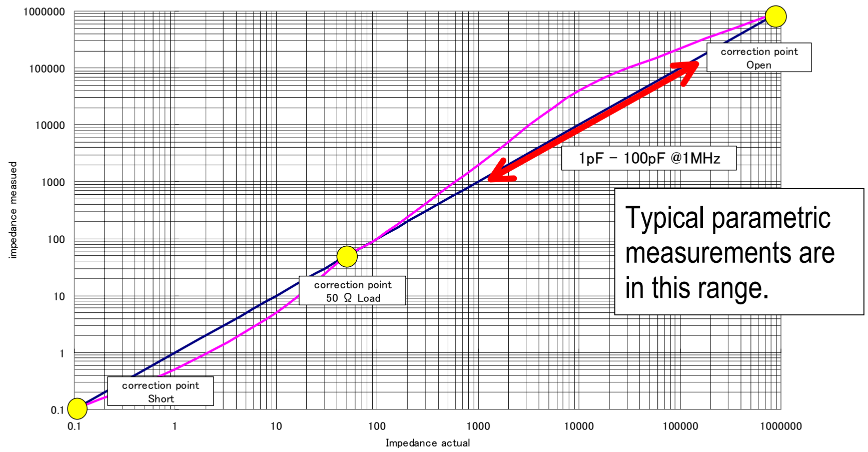


Capacitance meters typically expect a 50 Ohm environment. However, the switching matrix paths and the additional triaxial cable coming from the switching matrix outputs do not have a 50 Ohm characteristic impedance.



Capacitance meters require some very specific conditions to be met in order to supply accurate measurement results. However, it is very difficult to meet all of these conditions, particularly when measuring semiconductor devices.

Limitation of OPEN/SHORT/LOAD correction



Open/Short/Load correction is not perfect. Load impedance should be same range as the device impedance you want to measure.

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Unfortunately, the typical input impedance of a semiconductor device is very much higher than 50 Ohms.

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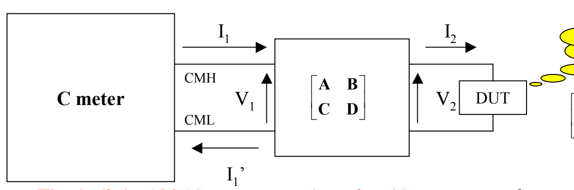
Open/Short/Load Correction Model

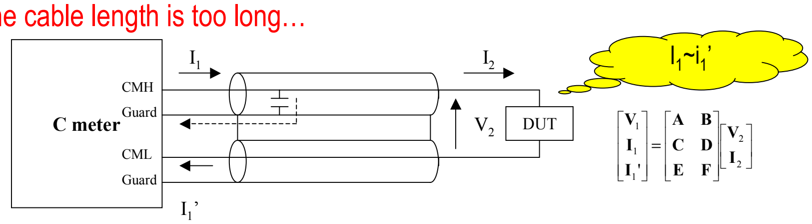
Ideal



$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

- The built-in 4284A compensation algorithm extracts four parameters using three (open/short/load) measurements.

If the cable length is too long…



$$\begin{bmatrix} V_1 \\ I_1 \\ I_1' \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \\ E & F \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix}$$

- Cables that are too long invalidate the assumptions. The number of port parameters becomes greater than four and **the built-in 4284A compensation routine does not work.**

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This slide shows why it is important to use cables no longer than 4 meters. Although this example deals with the 4284A, the situation with the 4294A is similar.

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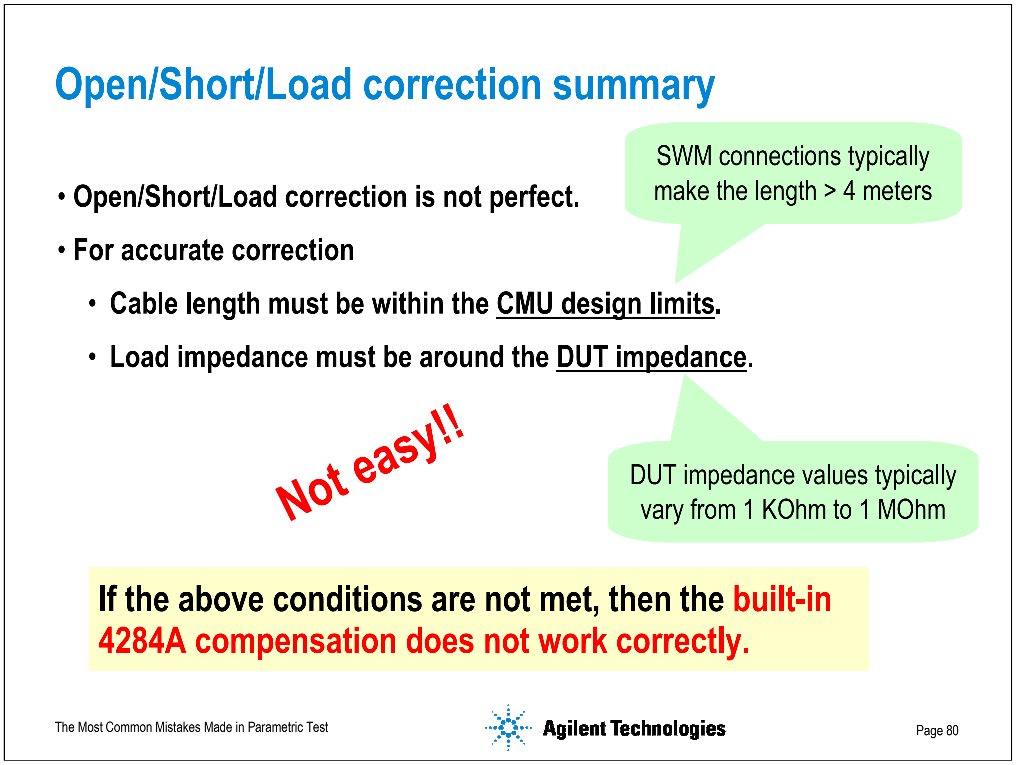

Until now, there have not been too many good ways to switch between CV and IV measurements using a switching matrix.

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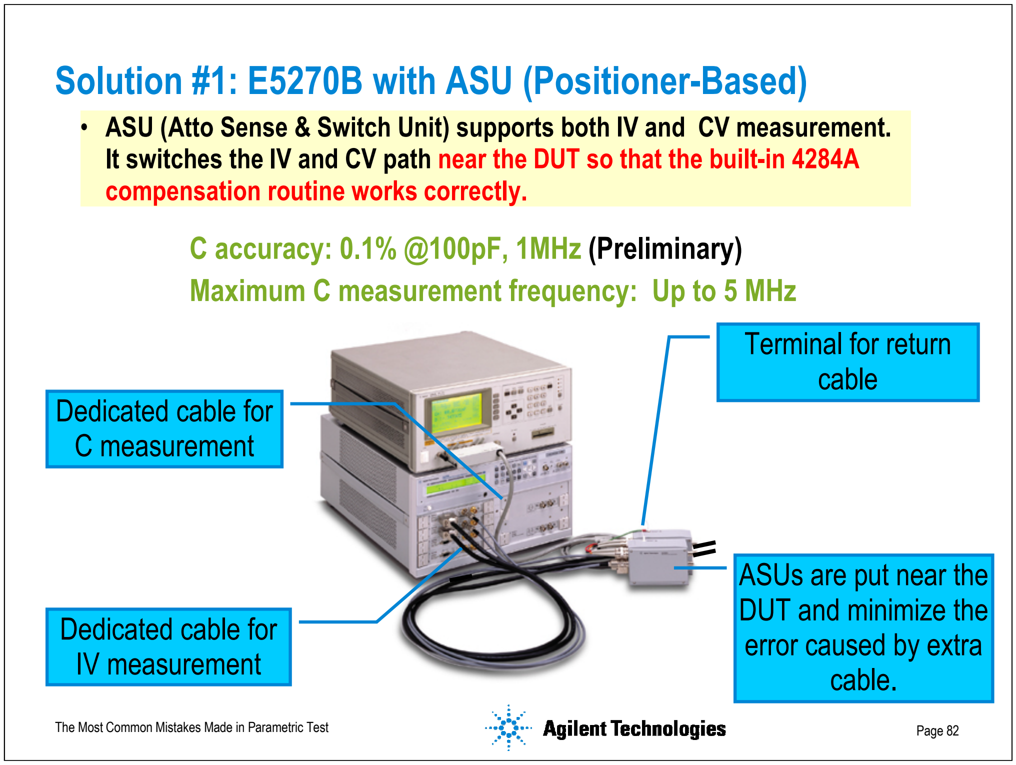
Our New Solutions Enable Accurate Measurement

- **We have new solutions for both positioner-based and prober-card based IV and CV measurement.**
- **Both solutions provide accurate CV / IV measurement.**

Agilent now has solutions for both positioner-based and probe card-base CV/IV measurement.

1. For positioner-based measurement, we have introduced the atto-sense and switch unit (ASU), which works with the E5270B high-resolution source/monitor unit (HRSMU). The ASU has two BNC inputs that are optimized for use with a capacitance meter. This allows you to switch between CV measurements (using a capacitance meter) and IV measurements (using the E5270B/4157B) without having to change any cables.

2. For probe card-based measurements, we have introduced the 41000 Series integrated Parametric Analysis and Characterization Environment (iPACE).



As you can see, for the case of positioner-based measurement the E5270B/4157B ASU solves the problems associated with using a capacitance meter in conjunction with a parameter analyzer. By keeping the CV measurement cable length fixed, the calibration and error correction required with a conventional switching matrix is eliminated.

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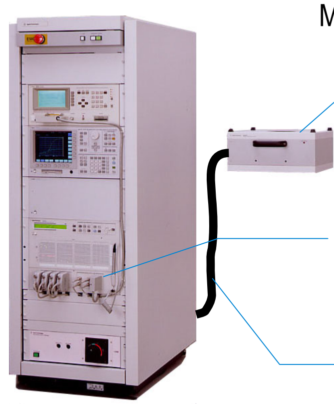
Solution #2: Agilent 41000 Integrated Solution (Probe-Card Based)

- **Integrated solution provides total measurement environment.**

C accuracy: <0.4% @100pF,1 MHz

Maximum C measurement frequency: 1 MHz



Return path is connected in the probe card interface.

Optimized CV input on switching matrix

Agilent provide connection cables matched to the compensation routine.

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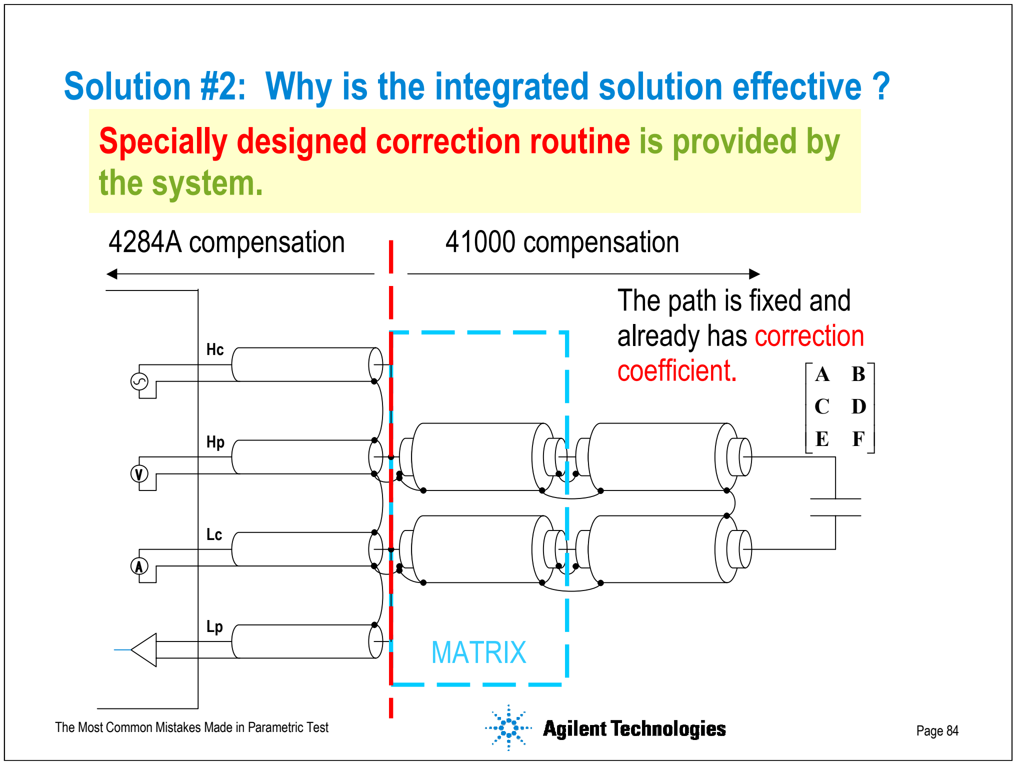
The 41000 Series solves the CV/IV measurement dilemma for the case of probe card-based wafer probing. The 41000 is shipped already racked and cabled, and all of the connections necessary for accurate CV measurement have already been taken care of for you.

In addition, the B2200A/B2201A switching matrices have built-in compensation routines for compensating capacitance measurements made through them.



The 41000 solution breaks the capacitance compensation up into two parts. The first part is taken care of by the capacitance meter. The second part is taken care of by the B2200A/B2201A switching matrices.

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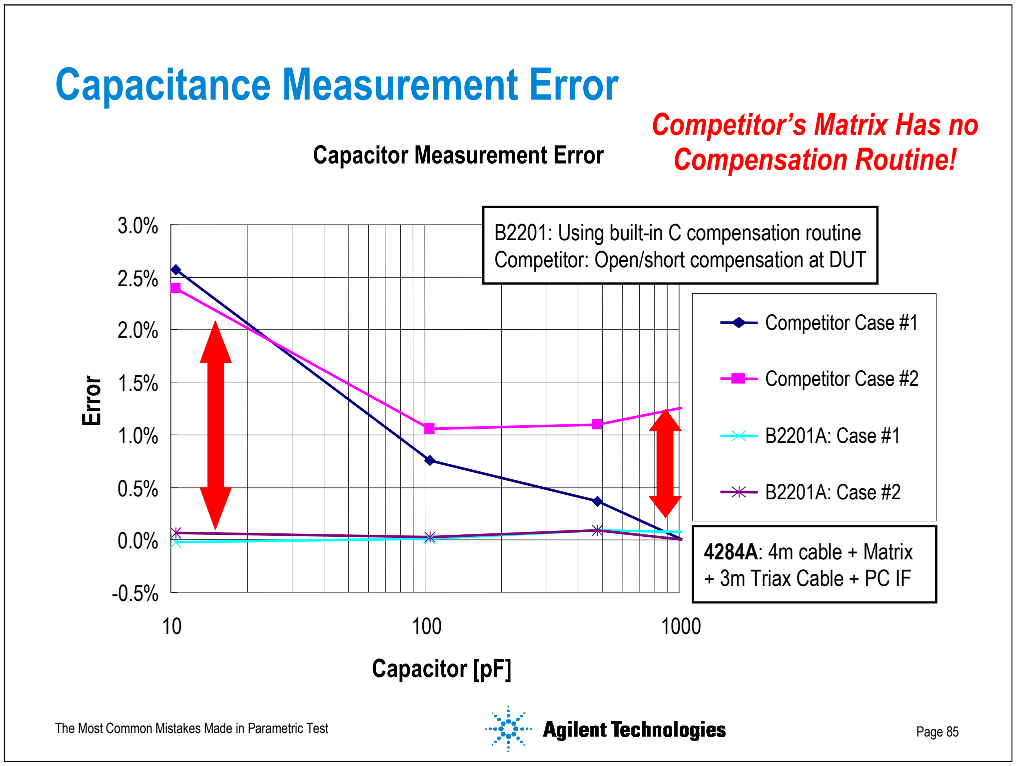

This plot shows the capacitance measurement error of Agilent's switching matrix (B2201A) versus that of our competitor. Comparable combinations of input/output connections are shown.

New Capacitance Measurement Solutions - Summary

- **CMU built-in correction is only effective under the designed condition and difficult to apply to SWM.**
- **Agilent can provide new two solutions for CV / IV measurement.**

Solution #1: E5270B + ASU : Maintains the CMU compensation limit.

Solution #2: 41000 iPACE : Total correction routine for matrix & cable.

Agilent can supply CV/IV measurement solutions for both positioner-based and probe card-based measurement environments.

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Conclusions / Summary

• A little understanding can go a long way towards helping you improve your parametric measurement skills.

• More information is available in our "Parametric Test Assistant CD" (Agilent Publication # 5988-9736EN)

• Live phone-based assistance is available by calling Agilent's US Customer Care Center at: 1-800-829-4444

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