Excerpt Edition

This PDF is an excerpt from Chapter 5
of the Parametric Measurement Handbook.

The
Parametric Measurement Handbook

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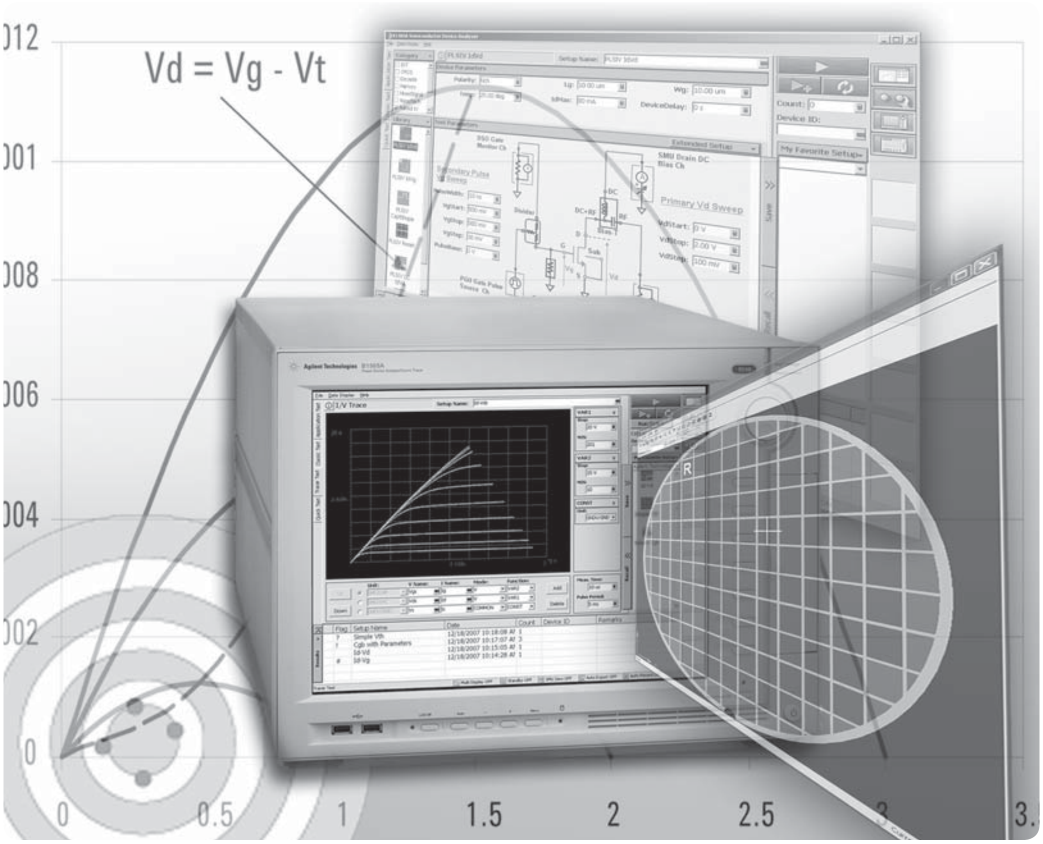


Agilent Technologies

Chapter 5: Time Dependent and High-Speed Measurements

"Experience is something you don't get until just after you need it." — Anonymous

Introduction

One of the most prominent trends in parametric test is the movement away from simple sweep and spot measurements (where measurement time is not an important part of the measurement) to measurements where the speed at which the measurement must be made is critical to the accuracy of the measurement. In some cases this requires new types of measurement modules other than SMUs, or even the integration of external instruments (pulse generators, oscilloscopes, etc.) with the parametric measurement equipment. However, some of the newer parametric instruments (such as the Agilent B1500A and B1505A) can make some impressive time sampling measurements just with their SMUs, so it is worthwhile to spend some time discussing all of the available measurement options.

Parallel measurement with SMUS

Parallel measurement is an important capability for all time dependent testing done with SMUs. True parallel measurement with SMUs is only possible when each SMU has its own analog-to-digital converter (ADC) available to it. The Agilent parametric instruments with this capability are the E5270B, the B1500A and the B1505A. For all of these instruments (except the E5260A Series), you can select either a shared high-resolution (HR) ADC or a per-SMU high-speed (HS) ADC for all of the various types of IV measurements as shown below.

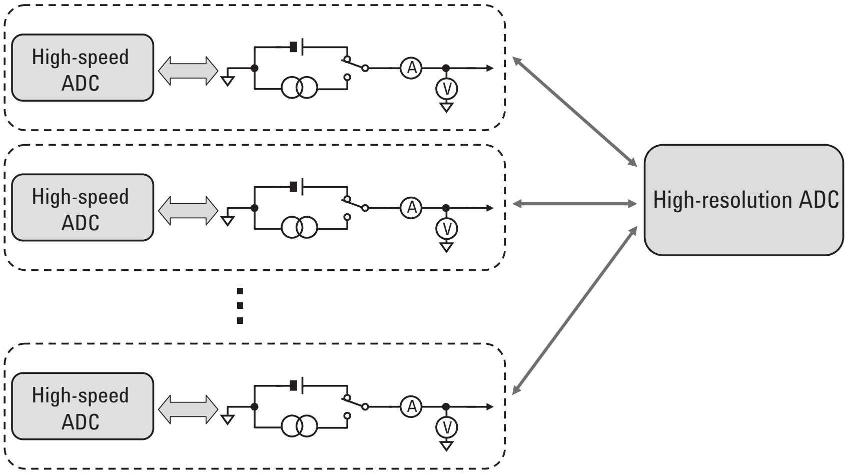


Figure 5.1. On instruments such as the E5270B, B1500A and B1505A you can select either the HS ADC or the HR ADC on a per SMU basis.

In Chapter 3 we discussed the multi-channel sweep mode of the B1500A and B1505A. This feature enables the B1500A/B1505A to make parallel measurements on multiple channels as long as the following conditions are met:

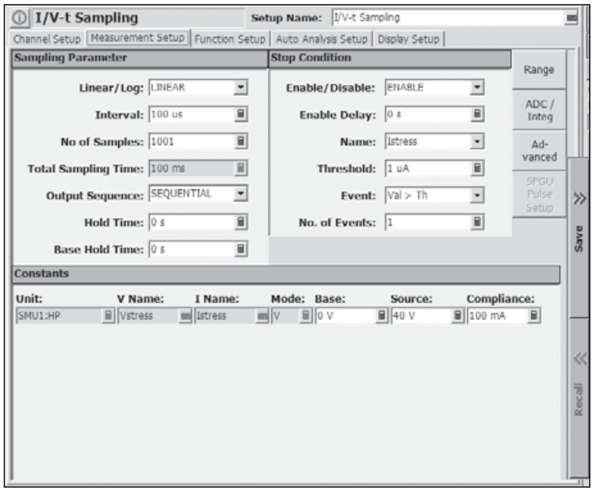
1. All parallel measurement SMUs must be in multi-channel sweep mode.
2. All parallel measurement SMUs must be using the HS ADC.
3. All parallel measurement SMUs must be in fixed measurement ranging.

If all three of these conditions are met, then parallel measurement occurs automatically. As was mentioned when we discussed multi-channel sweep mode, if the start and stop values for a VAR1 (sweeping) SMU are set to be the same then the SMU functions as a constant voltage or current source during the sweep (and it can also make parallel measurements).

One question often asked regarding this procedure is how to verify if the SMUs are indeed performing measurement in parallel (since there is no actual parallel measurement command). The suggested method to verify parallel test is to set both the HS ADC and HR ADC to very long integration times (4 or more PLCs). Repeat the measurement twice, the first time with the SMUs set to HS ADC and the second time with the SMUs set to HR ADC. It should be easy to detect a difference in the measurement times for these two cases (parallel measurement versus non-parallel measurement). Once you are convinced that the parallel measurement is working correctly, you can return the SMUs to their normal HS ADC setting and adjust the integration time for the HS ADC back to the value you want it at for the actual measurement.

Time sampling with SMUs

So far we have discussed making various types of sweep and spot measurements with SMUs, but we have barely mentioned the element of time. The 4155C, 4156C, B1500A and B1505A all possess a built-in time sampling capability that allows their SMUs to measure voltages or currents at specified intervals of time. This measurement capability is useful for certain types of reliability measurements such as time dependent dielectric breakdown (TDDB) where a device is placed under stress and continually monitored until an insulating layer ruptures. The B1500A/B1505A setup screen for a time sampling measurement is shown below.



Setup Name: I/V-t Sampling

Sampling Parameter

Linear/Log: LINEAR
Interval: 100 us
No of Samples: 1001
Total Sampling Time: 100 ms
Output Sequence: SEQUENTIAL
Hold Time: 0 s
Base Hold Time: 0 s

Stop Condition

Enable/Disable: ENABLE
Enable Delay: 0 s
Name: Istress
Threshold: 1 uA
Event: Val > Th
No. of Events: 1

Constants

Unit:	V Name:	I Name:	Mode:	Base:	Source:	Compliance:
SMU1:HP	Vstress	Istress	V	0 V	40 V	100 mA

Figure 5.2. Screen capture showing how to set up a time sampling measurement on the Agilent B1500A/B1505A (Classic Test mode).

In addition to specifying how frequently samples should be taken in time (the sampling "Interval"), there are many other parameters that can be specified. The "No of Samples" parameter specifies the maximum number of sample points to be taken, and in the case of the B1500A/B1505A this can be as much as 100,001 points. Moreover, it is possible to take samples in either linearly or logarithmically spaced intervals and a variety of different logarithmic sampling intervals (points per decade) are supported. It is also possible to specify a "Stop Condition", which will stop the sampling measurement before the maximum number of sample points is reached if the specified stop conditions are met. This is a very important capability, since it can reduce test times by stopping a measurement once an event of interest (such as the rupture of a gate oxide) has occurred. An example of this is shown below.

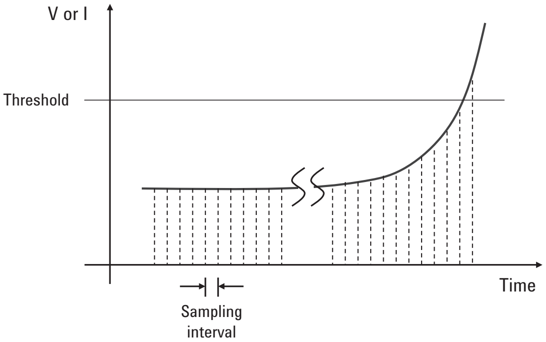


Figure 5.3. By setting up a stop condition you can terminate a time sampling measurement once an event of interest has occurred (such as the rupture of a gate oxide).

Sequential versus synchronous sequencing

For time sampling measurements it is sometimes important to consider how the SMU resources will be energized. For certain types of measurements you need to be very careful with respect to the order in which the SMUs are turned on. For other types of measurements, you may actually want ALL of the SMUs to be energized simultaneously. For this reason, Agilent parametric instruments that support time sampling (the 4155C, 4156C, B1500A and B1505A) all also support both sequential and synchronous SMU output sequencing. In the case of the B1500A/B1505A, if the “sequential” setting is selected then the SMUs will turn on in the order shown on the “Channel Setup” page (from top to bottom). However, if the “simultaneous” setting is selected then the SMUs will all turn on at the same time. Note: In both of these cases (sequential or simultaneous) the turn off order of the SMUs will follow the inverse order shown on the “Channel Setup” page (from bottom to top).

It is important to understand that the time sampling capabilities of the newer instruments (as well as their default settings) are different from those of the older 4145A/B. In many cases the failure to duplicate 4145A/B time sampling measurement results on the 4155C, 4156C, B1500A or B1505A can be traced to differences in the turn-on sequence of the SMUs. If you are having trouble correlating measurements results between these instruments then please check the settings on both instruments very carefully.

Setting up the time sampling interval

The most important point to understand when making time sampling measurements with SMUs is that accuracy trumps every other setting. This point is often missed by many users, resulting in much frustration and confusion. What is meant by this statement is that you cannot set up a time dependent measurement on an SMU that conflicts with the measurement accuracy you have specified. The SMU will always take as much time as it needs to meet the specified measurement accuracy, regardless of how fast you are telling it to make a measurement.

It is very easy to miss this point when setting up measurement conditions. For example, both limited ranging and auto ranging require the SMU to work its way down until the optimal measurement range (or range limit) is reached. Obviously, this takes time to complete. If you try to specify a time sampling interval that is smaller than the time required for the SMU to complete its measurement ranging, then the SMU will simply ignore the time settings and take however long is necessary to complete the measurement ranging. Therefore, it is always recommended to use fixed measurement ranging when performing time sampling measurements. Similarly, you cannot use power line cycle integration when making time sampling measurements. You must use an integration time of less than one PLC; in fact even when using integration times of less than one PLC you need to be careful not to specify an integration time that exceeds the measurement interval you are trying to achieve.

The exact procedure and limitations on setting up a time sampling measurement are idiosyncratic to the instrument that you are using. The following are important considerations to keep in mind if you set the sampling interval to less than 2 ms on the B1500A/B1505A:

1. All measurement channels must use the high-speed ADC; sampling intervals of less than 2 ms are not supported when using the high-resolution ADC.
2. If fixed measurement ranging is NOT selected, then the measurement channels automatically select the lowest fixed measurement range that covers the compliance value selected for that channel.
3. If the expected measurement time as determined by the number of averaging samples specified in the integration time is longer than the sampling interval, then the measurement channels will attempt to adjust the number of averaging samples so as to keep the specified sampling interval.
4. If multiple measurement channels are specified and all of the parameters are set up correctly, then all of the measurement channels will measure in parallel.

Advanced time sampling features (B1500A/B1505A)

We have spent a lot of time explaining how the SMUs make measurements in time sampling mode, but we have not discussed much about how they force voltage and current. In time sampling mode the B1500A and B1505A SMUs actually support some very useful sourcing features that have some important measurement uses. To begin with, let us review the basic output of an SMU during time sampling.

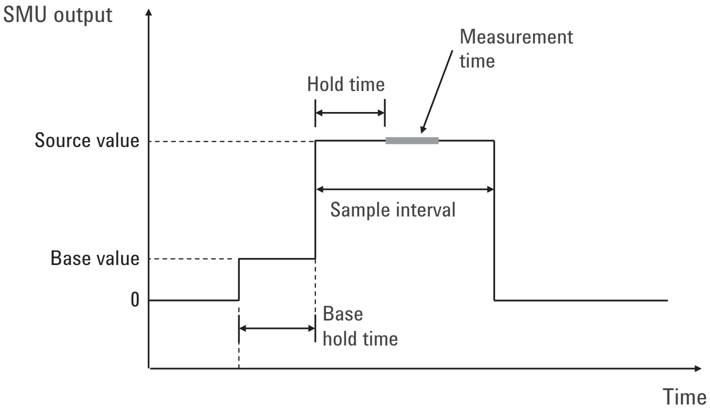


Figure 5.4. The basic SMU sourcing parameters for a time sampling measurement made on the B1500A/B1505A.

Note that both a “Base Value” and a “Base Hold Time” can be specified. It should also be pointed out that in both this diagram as well as the following diagrams the assumption made is that the measurement times are all less than the specified sampling interval (as is should be if everything is set up correctly).

The B1500A and B1505A also support a very useful feature (found under the “Advanced” settings) that permits SMU output to remain active AFTER the measurement completes. This feature is referred to as “bias hold after measurement”, and it can be set to either the base or source value. The figure shown below illustrates the case where the SMU has been set to hold its base value.

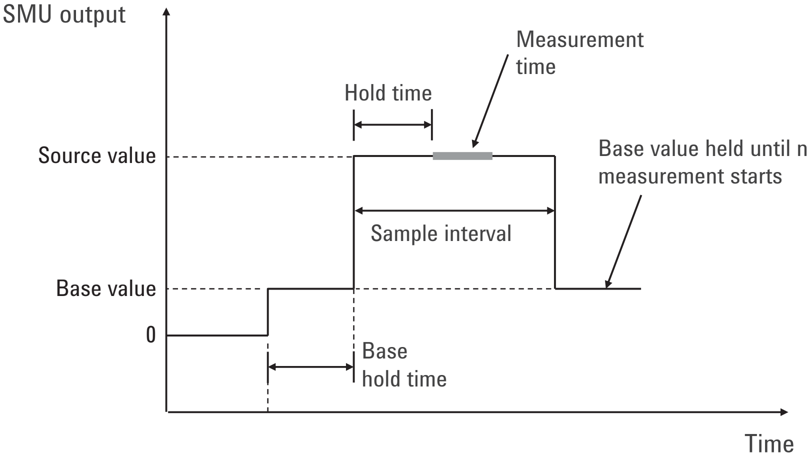


Figure 5.5. The B1500A/B1505A permit you to hold the bias to a non-zero value after measurement and this can be set to either the base or source value.

Note: It is important to understand that the bias is held only under two conditions:

1. When running multiple tests within another application test
2. When sequencing tests in "Quick Test" mode

The bias hold feature is NOT the same as the SMU Standby Mode, which energizes the SMUs to a specified value at all times (even when a measurement is not being made).

Finally, there is one other very interesting feature supported by the B1500A and B1505A in time sampling mode. This is the ability to specify a negative hold time. The figure shown below illustrates what is meant by a negative hold time.

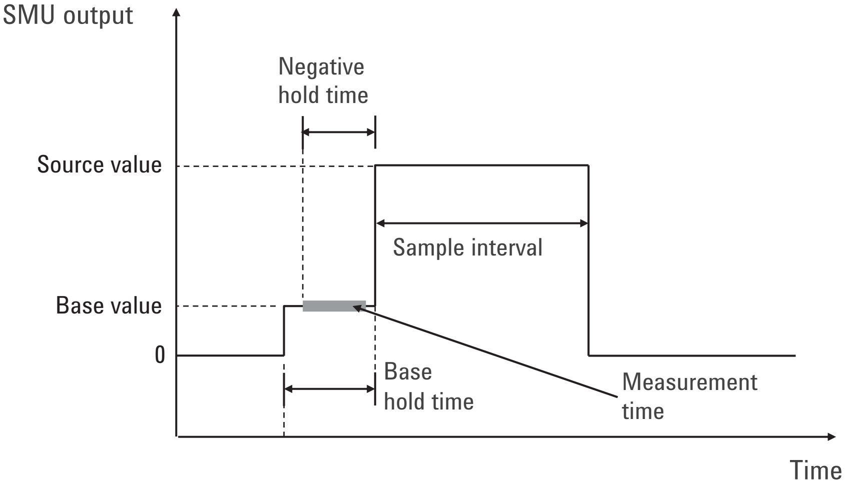


Figure 5.6. The B1500A/B1505A support a negative hold time feature that permits the SMU to start measuring BEFORE the SMU starts to supply stimulus.

It is important to note that the negative hold time feature is only supported when the sampling interval is less than 2 ms, and that the maximum negative hold time supported is –90 ms.

It turns out that these advanced time sampling features can be used very effectively for certain types of reliability measurements. In particular, negative bias temperature instability (NBTI) measurements can be performed very fast and effectively with SMUs by employing the aforementioned measurement features. Essentially, in an NBTI measurement we apply stress bias to a transistor gate and then periodically remove the stress to measure the transistor characteristics. However, if the stress drops to zero during the stress-to-measure transition then the transistor can "recover" and the measurement results will be invalid.

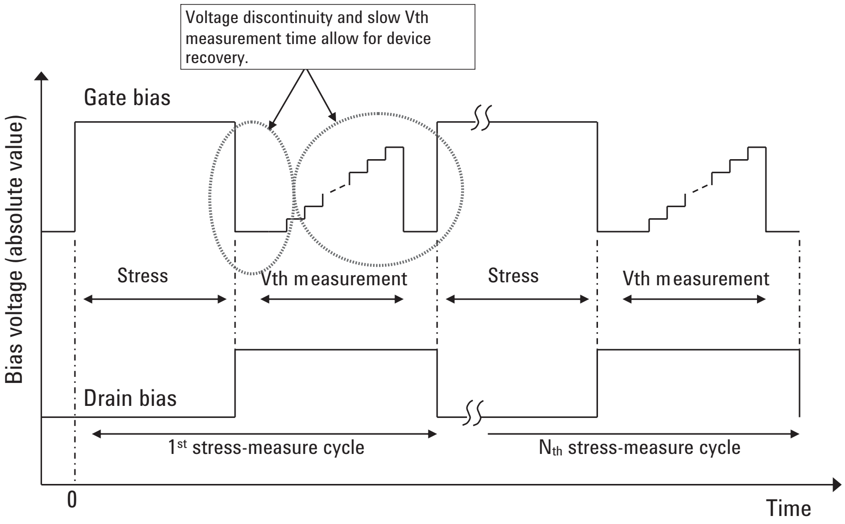


Figure 5.7. When making NBTI measurements it is essential that no discontinuities occur during the transition from stress to measurement.

By using the bias hold feature on the B1500A/B1505A we can make sure that this does not happen. In addition, by using the negative hold time feature we can actually start measuring while still in the stress phase. This ensures that no data is lost during the stress to measure transition. This technique is illustrated in the figure shown below.

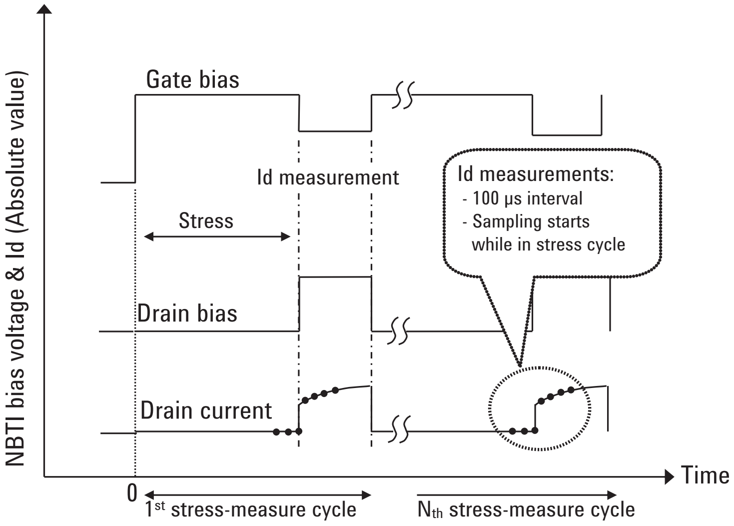


Figure 5.8. Making ultra-fast NBTI measurements using B1500A SMUs.

This technique is often referred to as "on-the-fly NBTI" measurement. The B1500A can make these measurements on a single SMU in 100 µs intervals. Using parallel measurement techniques, the B1500A can make parallel measurements using multiple SMUs in intervals given by the following equation:

$$t = 100\ \mu s + [20\ \mu s \times (n - 1)]$$

Here "n" is the total number of SMUs measuring in parallel. For more information please refer to the relevant B1500A application notes on this topic.

Maintaining a constant sweep step

It is sometimes desirable to perform a sweep measurement with constant sweep steps. However, it is important to understand that in a standard sweep measurement there is no guarantee of the measurement time to complete each point in the sweep. The following plot illustrates this situation.

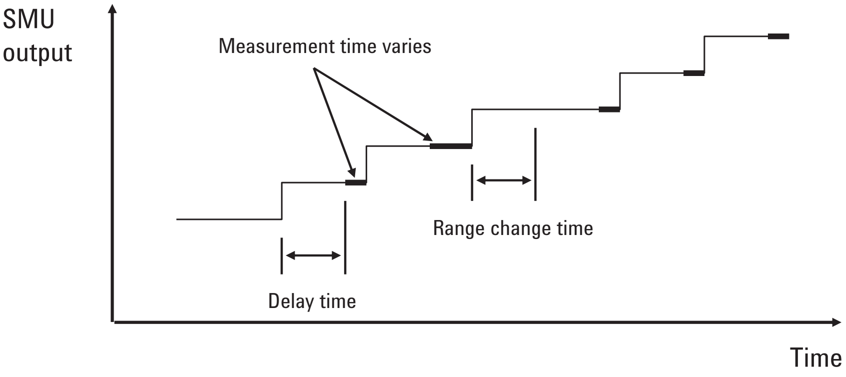


Figure 5.9. On a standard sweep measurement the amount of time spent at each point in the sweep can vary greatly.

There are two issues impacting the sweep measurement just shown. The first is that the measurement time varies from one measurement point to the next. The second is that if a range change occurs, then there will be a very long delay between measurement points.

There are ways to solve both of the aforementioned problems. Parametric measurement instruments support a feature known as "Step Delay". This feature allows you to specify the time that the instrument waits from the beginning of the actual measurement to when it increments to the next point in the sweep. Therefore, as long as the step delay is set to a value that is greater than that of the maximum expected measurement time then we can specify a constant total step time. Of course, this assumption is only valid if we do not encounter any range changes. To make sure that no range changes occur, fixed ranging should be used. The key thing to remember is that the fixed range chosen must include the maximum expected value to be measured during the sweep.

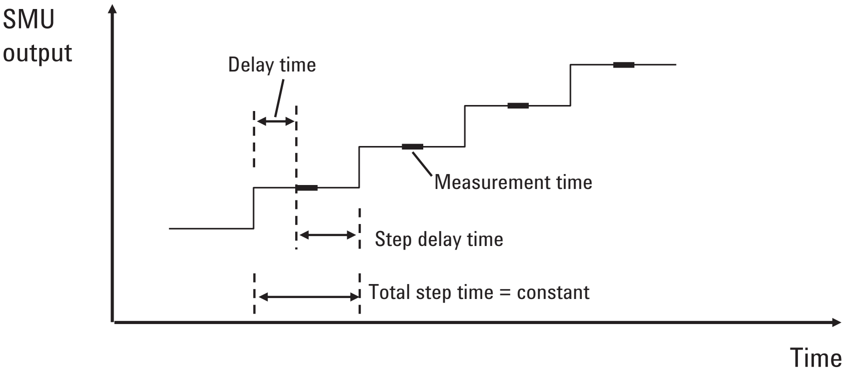


Figure 5.10. By using step delay and fixed measurement ranging, a constant sweep step time can be achieved.

There are some reliability measurements where maintaining a constant sweep step time is very important. The most common of these are the voltage ramp (VRAMP) and current ramp (JRAMP) tests. An example of a VRAMP test that uses the step delay feature to create uniform time steps for the voltage ramp is shown below.

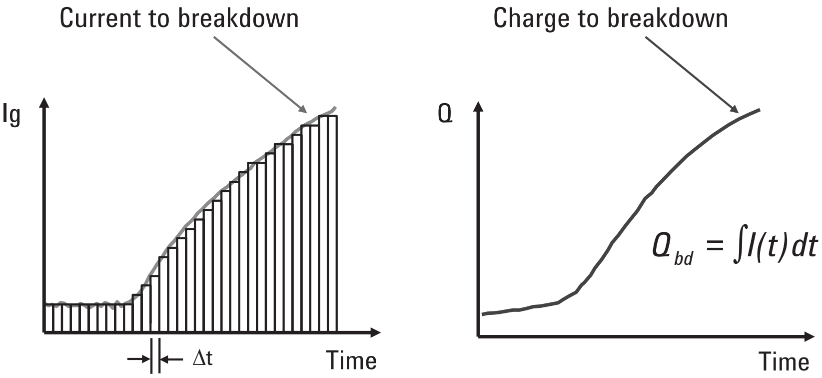


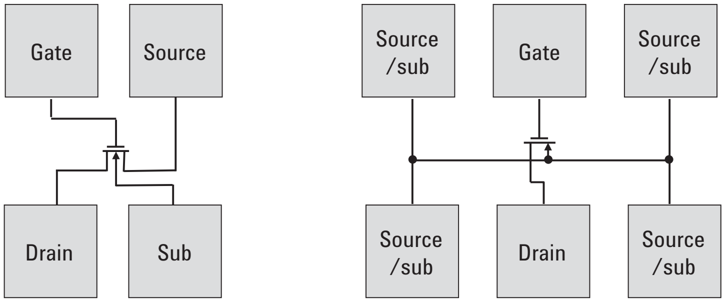
Figure 5.11. By using the step delay feature to create uniform time steps for a voltage ramp (VRAMP) sweep, it is very easy to calculate the total charge-to-breakdown (Qbd).

By maintaining a constant time step for the voltage sweep it is very easy to calculate out the charge-to-breakdown (Qbd) from the measured gate current at each point in the sweep using a simple rectangular approximation:

$$Q_{bd} = \int I(t)dt \approx \sum I \bullet \Delta t$$

High speed test structure design

To succeed in making high speed measurements you need more than just the correct measurement instrumentation; you also need to put sufficient forethought into the creation of the test structures that will be used to make the measurement. Attempts to make fast pulsed measurements with conventional DC test structures using DC positioners are unlikely to yield good measurement results. In general, fast pulsed measurements require test structures designed for a ground-signal (GS) or ground-signal-ground (GSG) measurement environment and RF positioners. The following figure illustrates this point.



Structure for conventional DC measurement

Structure optimized for RF measurement

Large overshoot and ringing

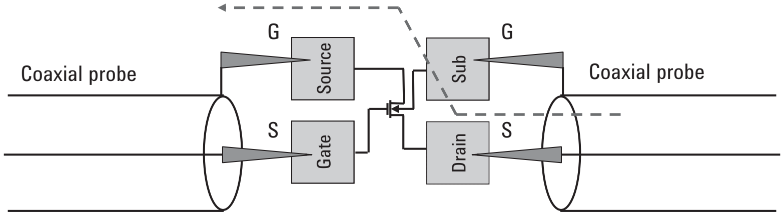
Clean pulse shape

Figure 5.12. Illustration showing how conventional test structures using DC probes do not yield satisfactory results when attempting to make fast pulse measurements.

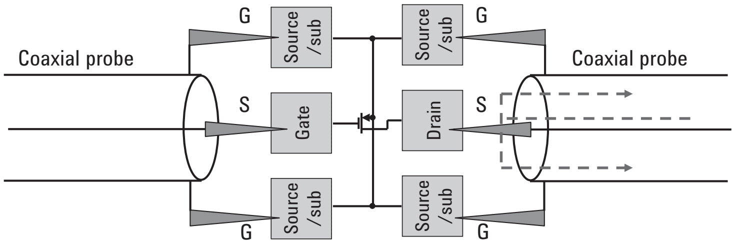
A photograph of a GSG RF probe tip is shown below.

Figure 5.13. A GSG probe tip. Note that this probe tip uses an SMA style coaxial connection. [Photo courtesy SUSS Microtech]

GSG probes do not necessarily produce superior measurement results to GS probes, since the results obtained also depend strongly on the pad layout and DUT structure. However, the following figure illustrates the reason why GSG probes can be superior to GS probes at high frequencies.



Some of the incoming signal energy must travel a long distance through the DUT to ground.
→ Large signal loss at high frequencies (not a concern for DC measurement)



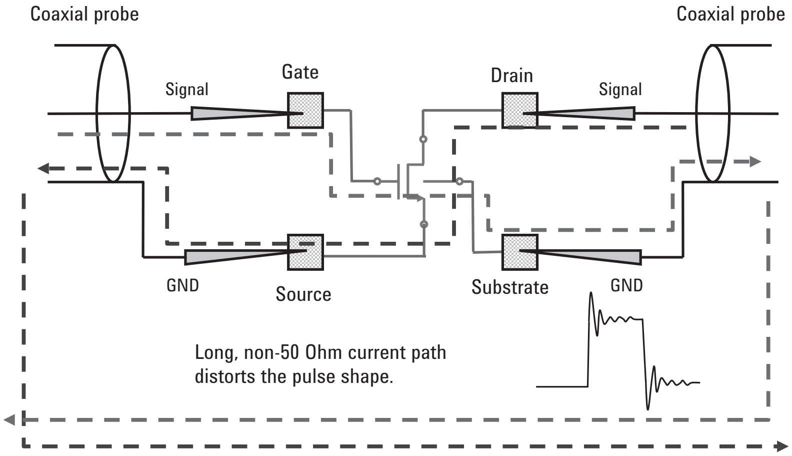
All of the incoming signal energy has a short return path through the DUT to ground.
→ Signal loss over frequency is minimized.

Figure 5.14. GSG probes can provide superior performance at higher frequencies relative to GS probes due to their shorter return path for the incoming signal energy.

The basic limitation of GS probes is that the energy entering the DUT can have a potentially long path length to return to ground, which results in significant signal loss. However, GSG probes have a much shorter return path to ground, which minimizes the signal loss over frequency.

Another consideration is the bandwidth of the RF probes that you are using. Since the shortest pulse widths that we use in parametric test are about 10 ns, at first thought it might seem that one or two hundred Megahertz of bandwidth would be sufficient. However, this is actually not the case. Remember that a square wave (pulse) is actually the summation of an infinite series of sine waves (odd harmonics). You need to have enough bandwidth in your RF probes (and indeed in your overall system) to support the higher harmonics, or you will get a distorted pulse shape. Therefore, to produce a clean 10 ns pulse you typically need at least 1 GHz of bandwidth.

In addition to the type of RF probes chosen and their bandwidth, the physical layout of the DUT also has a big impact on the integrity of the waveform pulse. In particular, placing the drain and source connections on MOSFET on opposite sides of the layout creates extremely long signal paths that will cause lots of ringing and greatly distort the shape of the applied pulse as shown below.

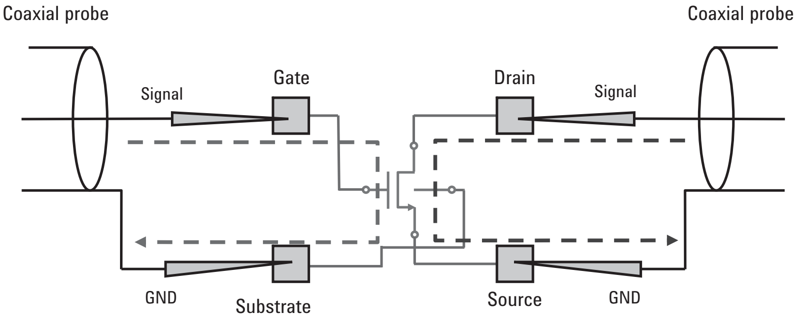


OK for pulse widths ≥ 200 ns

Figure 5.15. A GS probing arrangement with the drain and source on opposite sides as shown in this diagram can only support pulse widths of 200 ns or greater without causing pulse distortion.

Layouts with the drain and source terminals on opposite sides will generally only support pulse widths of 200 ns or greater.

A much better arrangement is to place the source and drain on the same side of the layout as shown below.

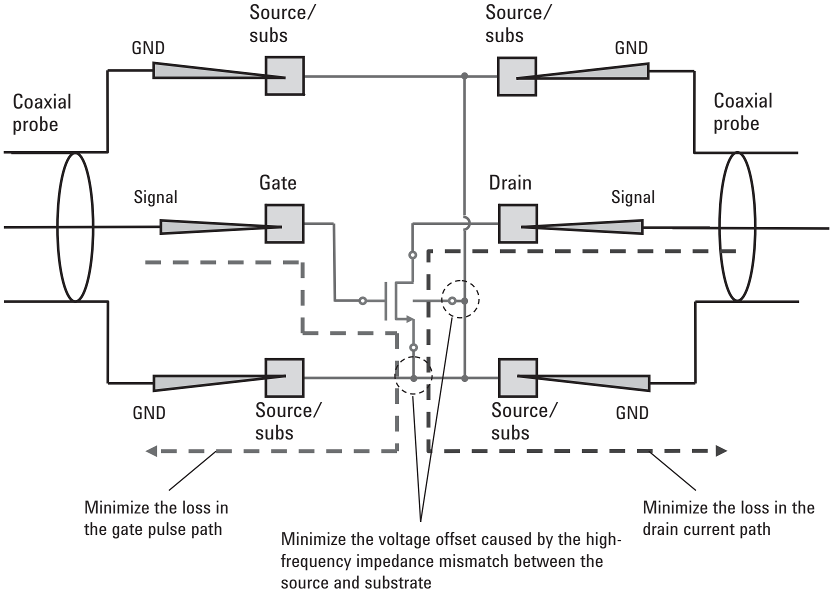


OK for pulse widths ≥ 100 ns

Figure 5.16. A ground-signal probing arrangement with the drain and source on the same side as shown in this diagram can support pulse widths down to around 100 ns.

Placing the source and drain on the same side creates a much shorter path for the signal energy, and a ground-signal pad layout can support pulse widths down to approximately 100 ns.

In order to achieve pulse widths down to 10 ns, both a ground-signal-ground pad layout and a structure design that shorts the source and substrate connections together are required. An example of this is shown below.



Minimize the loss in the gate pulse path

Minimize the voltage offset caused by the high-frequency impedance mismatch between the source and substrate

Minimize the loss in the drain current path

Good for pulse widths ≤ 10 ns

Figure 5.17. A ground-signal-ground probing arrangement with the source and substrate connections tied together as shown in this diagram can support pulse widths down to 10 ns or less.

Experimental results show that this layout scheme can reliably produce clean 10 ns pulses at the gate of the MOSFET.

To Get Complete Handbook

If you want to have more information, visit the following URL. You can get the complete "Parametric Measurement Handbook". This total guide contains many valuable information to measure your semiconductor devices accurately, also includes many hints to solve many measurement challenges. Now, English, Japanese, Traditional Chinese, and Simplified Chinese versions are available.

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Contents of Handbook

- Chapter 1: Parametric Test Basics
    - What is parametric test?
    - Why is parametric test performed?
    - Where is parametric test done?
    - Parametric instrument history
- Chapter 2: Parametric Measurement Basics
    - Measurement terminology
    - Shielding and guarding
    - Kelvin (4-wire) measurements
    - Noise in electrical measurements
- Chapter 3: Source/Monitor Unit (SMU) Fundamentals
    - SMU overview
    - Understanding the ground unit
    - Measurement ranging
    - Eliminating measurement noise and signal transients
    - Low current measurement
    - Spot and sweep measurements
    - Combining SMUs in series and parallel
    - Safety issues
- Chapter 4: On-Wafer Parametric Measurement
    - Wafer prober measurement concerns
    - Switching matrices
    - Positioner based switching solutions