Excerpt Edition

This PDF is an excerpt from Chapter 4
of the Parametric Measurement Handbook.

The Parametric Measurement Handbook

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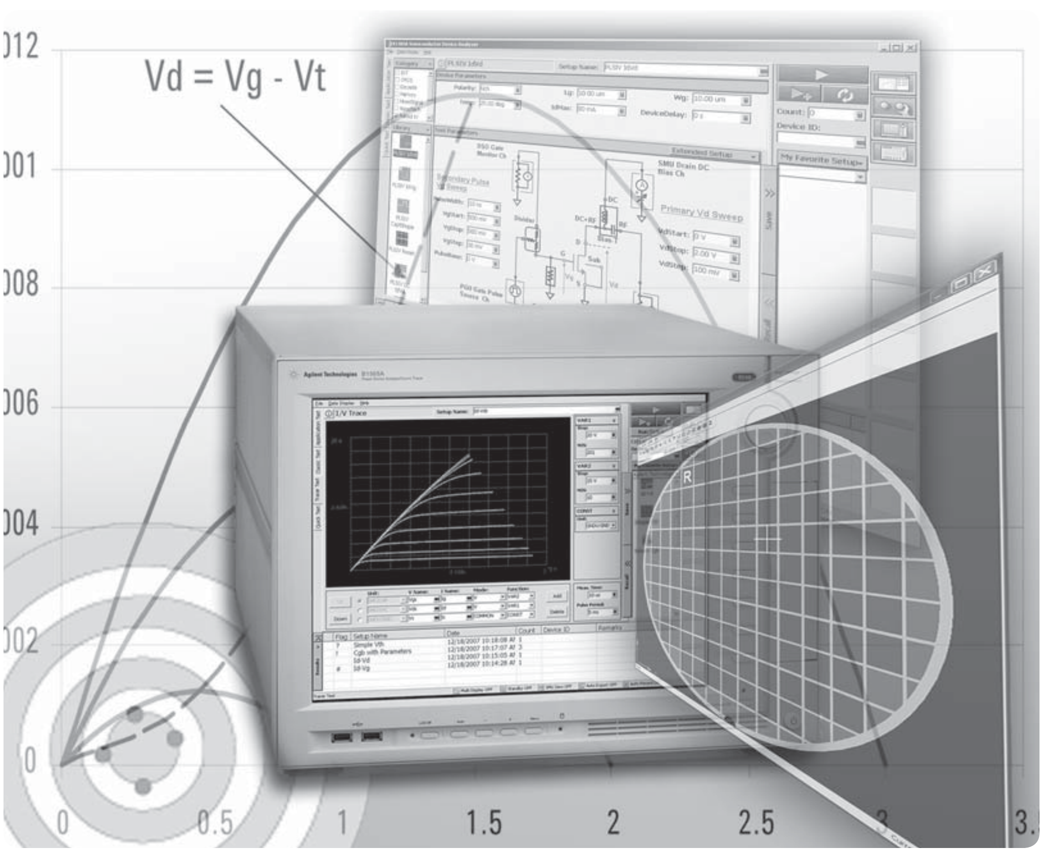

Agilent Technologies

Chapter 4: On-Wafer Parametric Measurement

"One must learn by doing the thing; for though you think you know it, you have no certainty until you try." — Sophocles

Introduction

The vast majority of parametric measurements are performed on-wafer. Obviously, this implies that you need some sort of a wafer prober to make these measurements. What is often missed by many engineers performing on-wafer parametric measurements are the profound effects that various factors such as the wafer chuck, cables, wafer probes and switching matrix (if used) can have upon their measurement results.

Fully automatic versus analytical wafer probers

Fully automatic wafer probers are designed to be used in production environments in conjunction with either parametric or functional test equipment. Fully automatic wafer probers can test an entire cassette or FOUP (front-opening unified pod) of wafers at a time, and they have the ability to automatically load and align a wafer for testing. Fully automatic wafer probers are virtually always used with some sort of a probe card and switching matrix. Due to their size, cost, and complexity, fully automatic wafer probers are used almost exclusively in production test environments with high-volume production testers. Since this handbook is primarily focused on parametric test instruments, we will not spend any additional space discussing them.

Analytical wafer probers are designed to be used in laboratory environments, and they come in both manual and semi-automatic versions. Manual wafer probers do not possess any electrical motors to automate any part of the wafer alignment and stepping process, but must instead (as their name implies) be manually adjusted each time that you want to move to a new location on the wafer. In contrast, most semi-automatic wafer probers possess the capability to automatically align an individual wafer; however, they typically do not support any sort of automated wafer loading and they require the manual loading of each wafer. Semi-automatic wafer probers can be used with probe cards and switching matrices, but it is more common to see them used with multiple individual positioners (probes) for maximum measurement flexibility. Most semi-automatic wafer probers also do support automated testing across an entire wafer in conjunction with some sort of parametric instrumentation.

Figure 4.1. Some examples of semi-automatic wafer probers.

Wafer prober measurement concerns

It should be clear upon some reflection that the wafer prober measurement environment has a significant impact on the quality of parametric measurements that you can obtain. Unfortunately, many times these effects are not adequately accounted for by users trying to make parametric measurements. Some of the key issues are as follows.

1. Limited current noise floor – An inadequately shielded wafer prober will greatly increase the noise floor of the measurement environment.
2. Slow measurements – Capacitance and piezoelectric effects can significantly impact the speed at which parametric measurements can be made.
3. Low and high temperature measurements – Low and high temperature measurements both present issues in terms of moisture and noise.

Chuck isolation

The basic rules for proper guarding and shielding discussed in Chapter 2 take on great significance when applied to the wafer probing environment. It is important to understand that a wafer chuck is an extremely large capacitor and that it can also act as a large antenna (collecting random noise). Therefore, optimal measurement performance is obtained through the use of a guarded Kelvin wafer chuck as shown below.

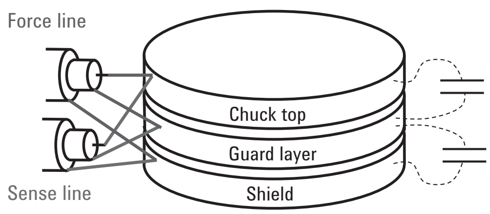

Figure 4.2. A guarded Kelvin wafer chuck can eliminate the effects of the parasitic chuck capacitance and greatly reduce the leakage from the chuck to the outside environment.

By using a guard layer in the wafer chuck, the effects of the parasitic chuck capacitance and the leakage currents through the wafer chuck can be virtually eliminated. The following plot compares the settling time for both guarded and unguarded wafer chucks, and it is clear that for the case of the guarded chuck the necessary wait time before a measurement can begin is greatly reduced.

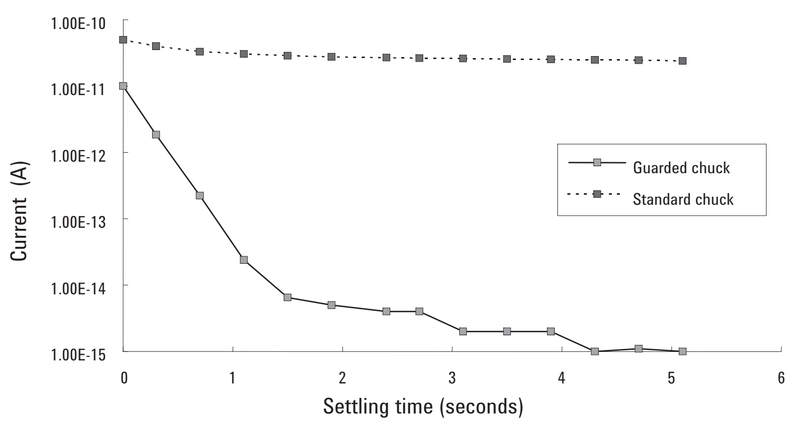

Figure 4.3. Plot comparing the settling time for both guarded and unguarded (standard) wafer chucks.

In addition to guarding the wafer chuck, if the guard can also be placed above the wafer being measured then noise can be reduced further and an optimal low-noise measurement environment is guaranteed. Such a measurement scheme is shown below.

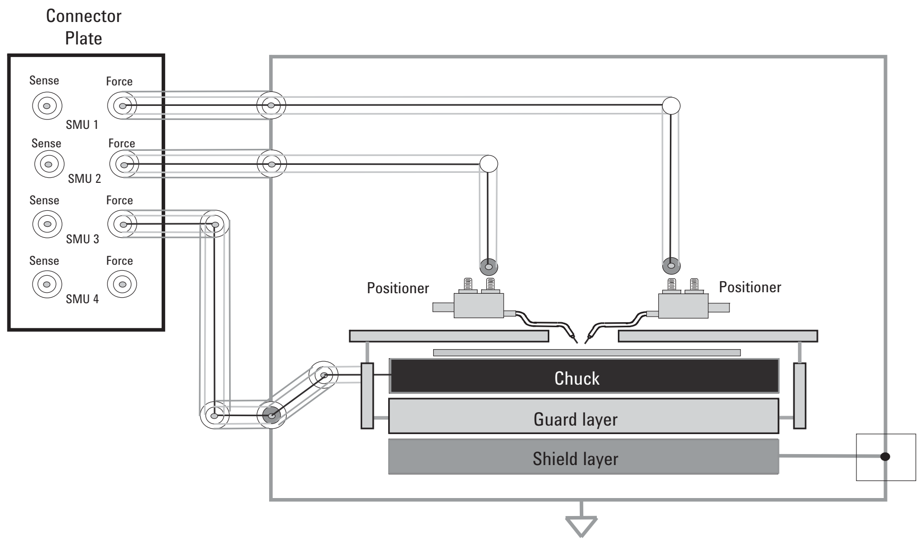

Figure 4.4. A completely guarded and shielded wafer prober environment (Note: Scheme shown is Cascade Microtech's patented AttoGuard® technology).

Low and high temperature measurement issues

Performing parametric measurements at low and high temperatures on-wafer presents the following measurement challenges.

1. High electrical noise caused by the thermal control circuitry.
2. Slow measurement times due to parasitic capacitance.
3. Large transient noise after wafer chuck moves.
4. Frost induced moisture leakage.

We will proceed to examine each one of these in-turn.

The electrical noise generated by the thermal control circuitry is probably the single greatest source of error when making low-level measurements on-wafer at temperature. While it is not possible to completely eliminate all of the effects of this circuitry, many analytical wafer prober companies have mitigated them to a great extent. The graph shown below shows the noise current associated with a standard triaxial wafer chuck as the chuck temperature varies over time.

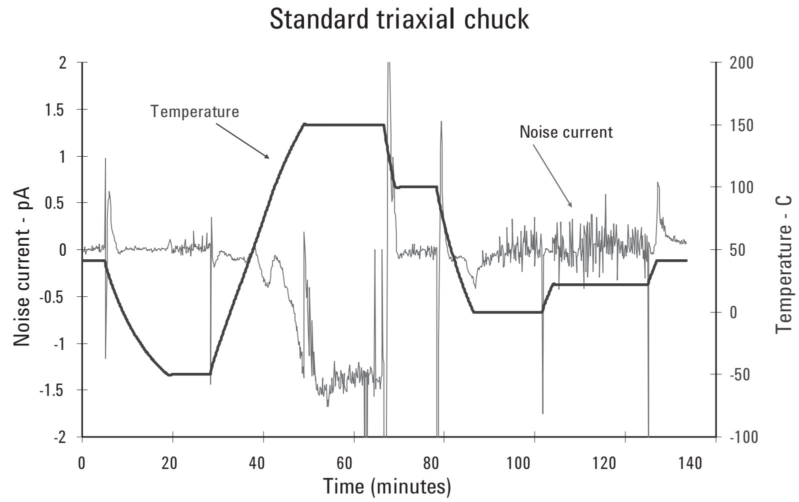

Figure 4.5. Noise current for a standard triaxial wafer chuck as the temperature varies over time.

In contrast, the following graph shows the noise current for a well-designed thermal wafer chuck.

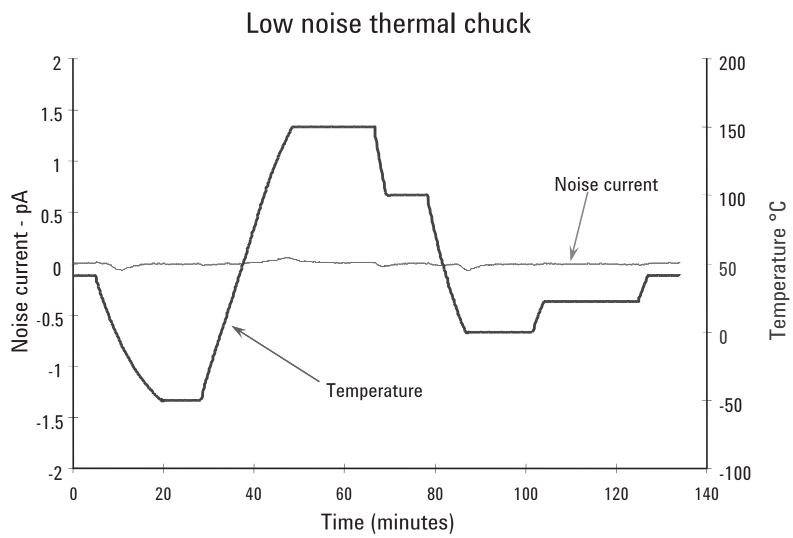

Figure 4.6. Noise current for a well-designed low-noise thermal wafer chuck.

In the end you get what you pay for, so it does not make sense to try and make low-level measurements at high or low temperatures on anything other than a wafer chuck specifically designed for that purpose. Before purchasing any analytical wafer prober with a thermal chuck option you should very carefully evaluate its low-current noise performance to make sure that it meets the requirements of your parametric measurements.

In addition to reducing noise on the wafer chuck, it is important to reduce noise and capacitance effects caused by the probes. Ceramic bladed probe tips are the best solution for making on-wafer measurements at high temperatures. Bladed probe tips can easily handle temperatures of up to 300 degrees Celsius, and they have minimal residual capacitance. A picture of a ceramic bladed probe tip for positioner-based wafer probing is shown below.

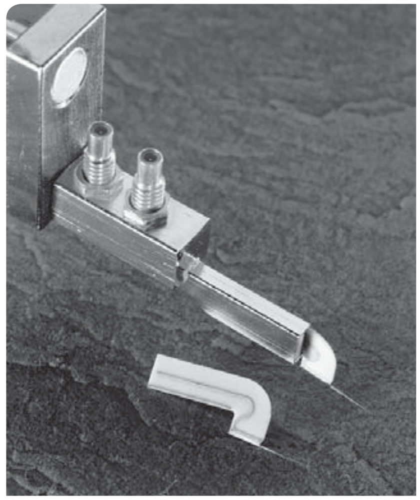

Figure 4.7. Ceramic bladed probe tips are the best solution for on-wafer high-temperature measurement. [Note: Photo courtesy of Cascade Microtech]

Note that these types of probe tips are also easily replaced if they become damaged.

The same type of methodology should be implemented when using probe card schemes (which will be discussed later in this chapter). However, in the case of probe cards the juxtaposition of many signal lines close together adds some design complexity. The key is to shield the entire probe card within a metal enclosure to isolate the signal lines as much as possible from thermal noise. An example of a fully guarded ceramic probe card for high temperature measurement is shown below.

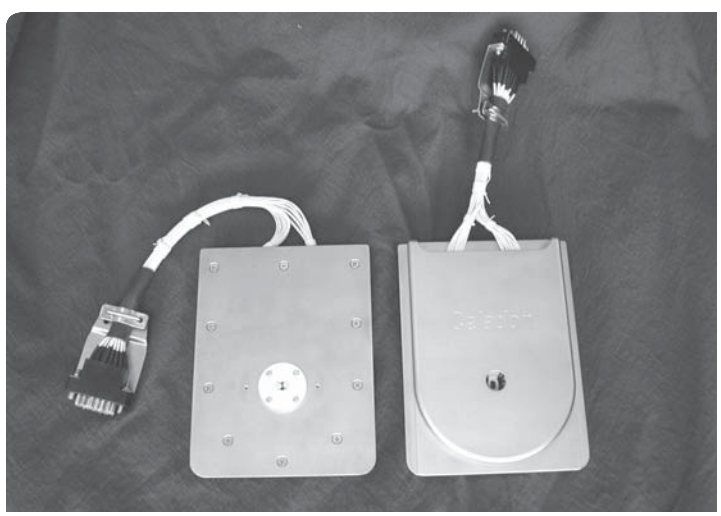

Figure 4.8. A ceramic bladed probe card with full shielding that works from –65 °C to +300 °C. Note: This is a picture of Cascade Microtech's Attofast™ probe card.

On a semiautomatic wafer prober the electronics and cable connections used to move the wafer chuck and to control its temperature have a strong impact on low-noise measurements, and these are exacerbated at higher temperatures. There is no single “magic bullet” that can completely eliminate these noise sources, but sound design principles can mitigate them. Some key points to look for in a wafer prober are listed below.

1. Low triboelectric effect materials to minimize the electronic charge generated via friction.
2. Low dielectric absorption materials to minimize the residual capacitive charge.
3. Low noise design through proper shielding.

The final issue to consider when making on-wafer low temperature parametric measurements is frost, which is related to the dew point. Moisture degrades parametric measurement significantly, and can cause high residual capacitance, elevated leakage currents, and increased noise. For this reason, it is often recommended to “bake” a wafer chuck at +200 °C for twenty-four hours prior to making any at temperature parametric measurements. In any case, low temperature measurements require an atmospheric flow (using either clean dry air or nitrogen) to prevent frost from forming. However, as the graph shown below indicates, increasing the air flow also increases the noise.

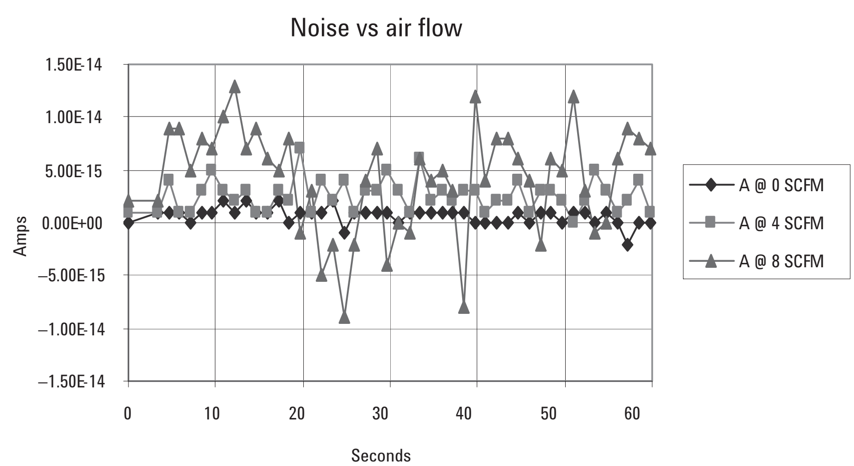

Figure 4.9. The effect of air flow on noise.

Therefore, the best probing systems are those that can achieve (for example) frost-free operation at –55 °C with minimal air flow. ***Note:*** An SCFM flow of less than 1 is probably sufficient for most measurements.

DC and RF wafer probes

For analytical wafer probers, there are two distinct types of positioners: DC and RF. Although many people might assume that RF probes are only required for true RF measurements made in the GHz range (such as S-parameter extraction), this belief is not correct. Capacitance measurements made above 5 MHz may require RF probes in order to achieve satisfactory measurement results, and many high-speed pulsed measurements require RF probes to avoid creating ringing on the pulse edges. Therefore, it is important to understand the differences and limitations of both DC and RF probes.

There are several key points to keep in mind when designing test structures for RF wafer probes.

1. RF wafer probes are typically mounted in fixed positions on the wafer prober (180 degrees opposite to each other), so whatever structures you place on the wafer must adhere to this limitation.
2. RF wafer probes primarily come in ground-signal (GS) or ground-signal-ground (GSG) configurations, and they are available in only certain pad pitches (typically ranging from 50 μm to 250 μm).
3. The probes themselves should be separated by at least 200 μm to avoid crosstalk.
4. All grounds should be connected together.
5. Any biasing or control pads should be completely out of the main signal path.
6. RF probes require BNC cabling and usually use an SMA style connector.

A generic example of a test structure adhering to these guidelines is shown below.

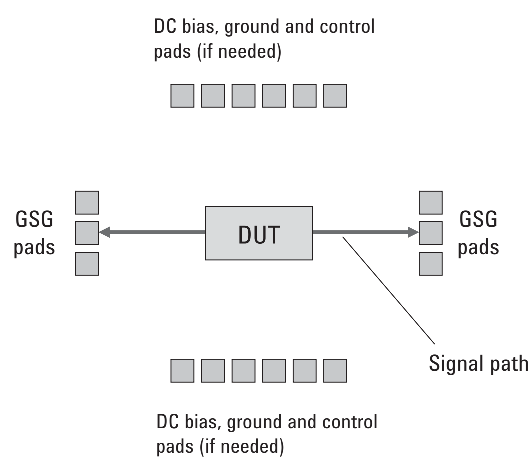

Figure 4.10. The proper way to layout a structure for use with RF positioners.

A picture of RF probes used for on-wafer measurement is shown below.

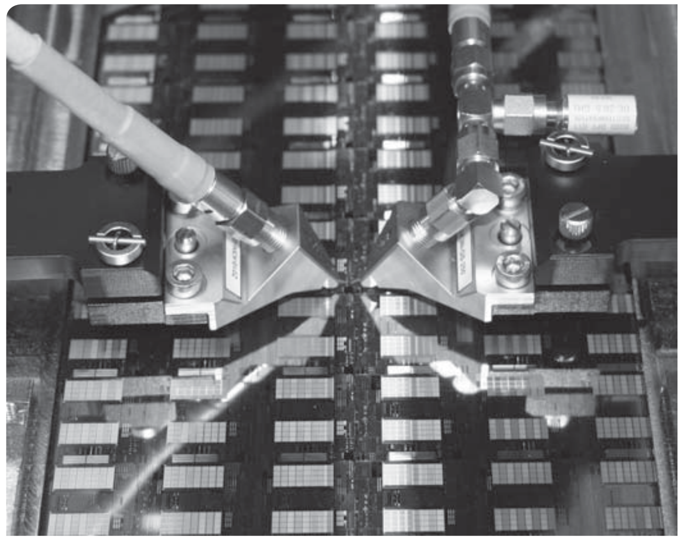

Figure 4.11. An example of on-wafer measurement using RF wafer probes. [Note: Photo courtesy of SUSS Microtech]

RF positioner device layout and design will be discussed further when we cover high-speed pulsed measurement in Chapter 5 and high-frequency capacitance measurement in Chapter 8. Note that the RF probes use SMA connectors, so BNC to SMA connector adapters will be required if you are trying to connect up instruments such as capacitance meters.

Switching matrices

Introduction

Although switching matrices do not necessarily have to be used in conjunction with on-wafer semiconductor measurements, it is very rare to see them used outside of this type of a measurement environment. When making on-wafer measurements, a switching matrix can both facilitate faster measurement and simplify the connection environment (for example switching between IV and CV measurements). A photo of a switching matrix for use in parametric test is shown below.

Figure 4.12. The Agilent B2200A femtoamp low leakage switch.

The basic concept of a switching matrix is not hard to understand. A switching matrix consists of a series of inputs and outputs; connections between the inputs and outputs can be made by closing one or more relays. Since virtually all connections in parametric test are made with triaxial cables, almost all switching matrices convert some number of coaxial inputs into triaxial outputs. While the number of inputs on a switching matrix is fixed, the number of outputs is usually determined by the number of cards installed in that matrix mainframe. Each card will typically add some number of outputs to the configuration. An example of a switching matrix card is shown below.

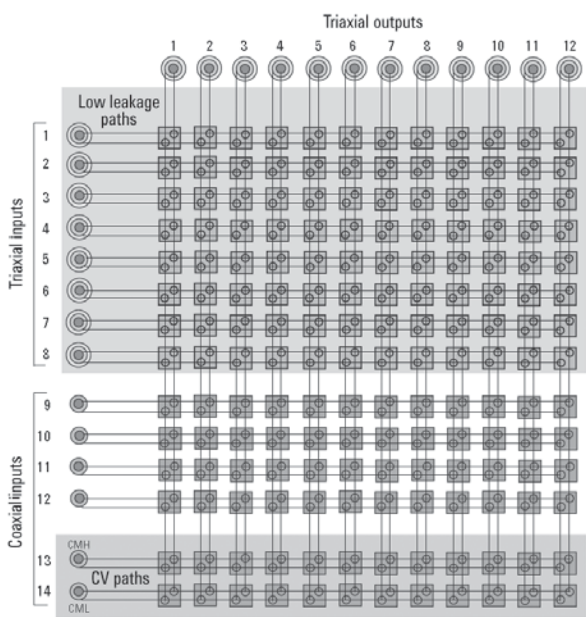

Figure 4.13. An example of a switching matrix card with both triaxial and coaxial inputs (as well as a dedicated path for CV measurement)

There are some key takeaways from the schematic just shown. The first of these is that not all triaxial switching matrix paths are necessarily "low-current". In the above schematic this is true, but this is not always the case for all switching matrix cards. The second observation is that a switching matrix converts all inputs (triaxial and BNC) into triaxial outputs. This is extremely convenient since eliminates the need to worry about triaxial to BNC adapters. The third (and final) observation is that some matrix cards have a dedicated path for capacitance measurement. However, we will defer discussion of making CV measurements through a switching matrix until we reach Chapter 8 and discuss capacitance measurements.

Probe cards and module testing

In order to understand the benefits of a switching matrix when making on-wafer measurements one must first understand how parametric test structures are organized on the wafer. Parametric test structures are typically organized into modules with some sort of regular pad organization (such as two rows of twelve pads). When used in conjunction with a probe card designed to fit the module pad configuration, a switching matrix permits the testing of all of the devices in that module without the need to physically move the probes. By using the switching matrix to connect and disconnect the DUTs from the parametric measurement resources, the time associated with physically moving the probes from one device to the next is eliminated. The following figure shows a photo of probe card tips contacting a test module on a wafer.

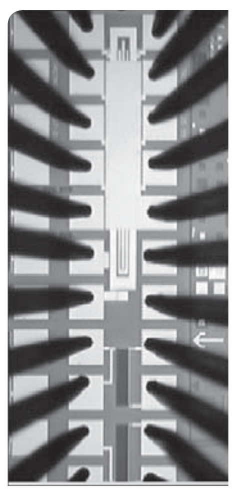

Figure 4.14. A photo showing a probe card contacting a module on-wafer.

Even in a semi-automatic wafer prober environment, the use of a probe card can significantly improve test throughput.

It should be obvious that in order to take full advantage of a switching matrix and probe card solution, some sort of software test shell is necessary to control everything. The key requirements of this software are shown below:

1. The ability to coordinate testing with the wafer map stored on the semi-automatic wafer prober.
2. The ability to specify sub-die moves so that different modules within a die can be tested.
3. The ability to store and recall switching matrix settings to connect to a particular device to be tested.
4. The ability to store measurement results for each device tested along with information as to the exact location (both die and sub-die) of that device on the wafer.

Agilent Technologies' EasyEXPERT software possesses all of these capabilities and can be used to automate the testing across a semiautomatic wafer prober.

In order to perform automated wafer testing using Agilent EasyEXPERT you must first set up a wafer map on the semiautomatic analytical wafer prober that you plan on using. An example of this is shown below.

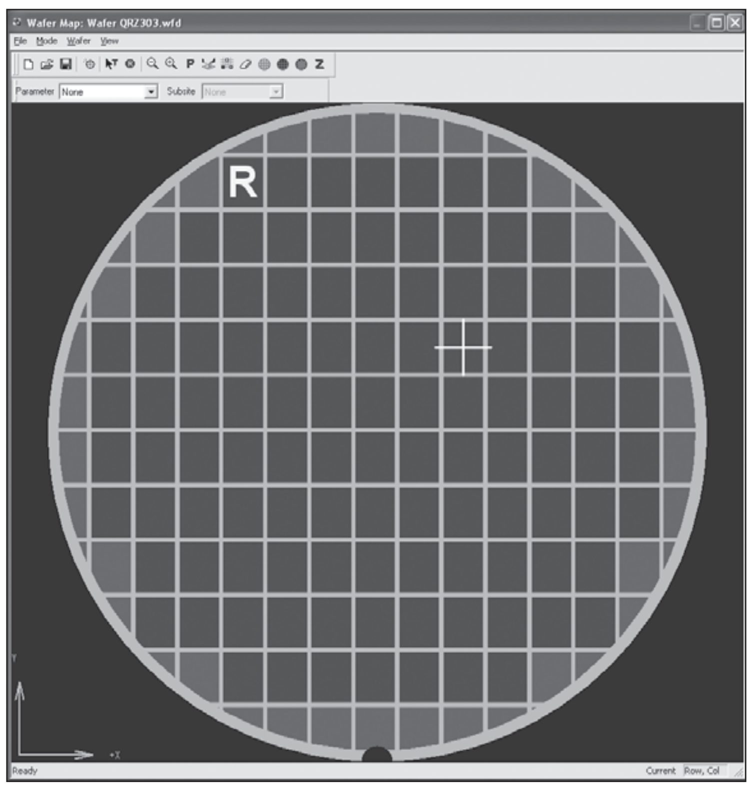

Figure 4.15. Setting up a wafer map on a semiautomatic wafer prober in preparation for automated wafer probing.

Once the wafer map is set up you can start the automated testing by calling up the “Repeat Measurement Setup” window by clicking on the repeat button in the upper right corner of the main EasyEXPERT screen.

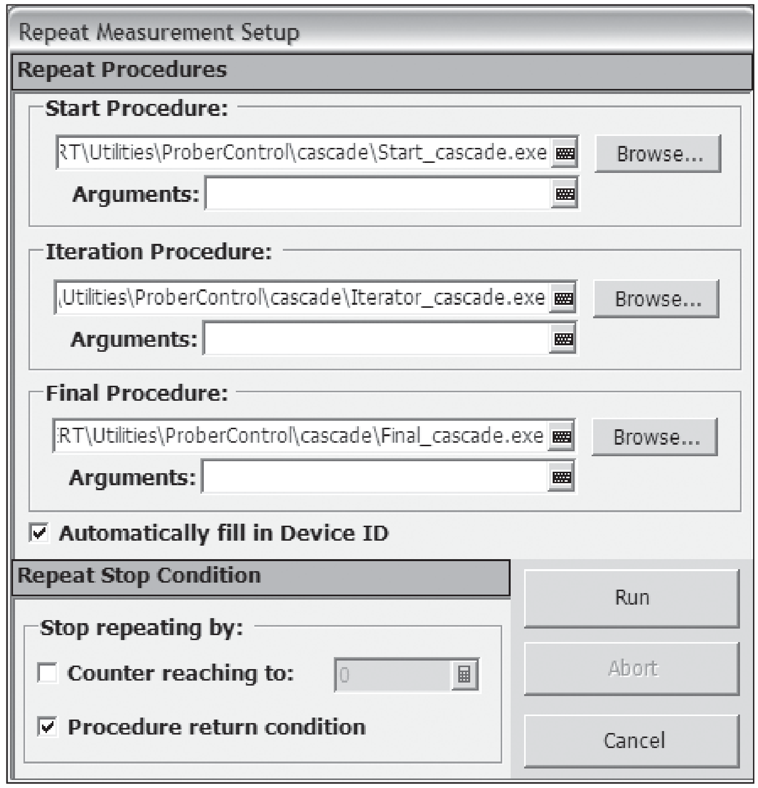

Figure 4.16. The Repeat Measurement Setup screen allows you to set up the conditions to automatically step and repeat one or more measurements across a wafer.

Note: You must have the data auto-record feature turned on in order use this feature.

EasyEXPERT has built-in wafer prober drivers for Cascade, SUSS and Vector semiautomatic wafer probers. In addition, sample source code is available so that you can create your own wafer prober drivers if necessary. The prober driver files can be found in the following location: Program Files\Agilent\B1500A\EasyEXPERT\Utilities\Prober Control. Each supported prober has a file folder, and there are several executable files located in these file folders. In the “Repeat Procedures” section of the “Repeat Measurement Setup” window the correct executable file can be selected using the “Browse” button. For each of the three lines, Start, Iteration and Final, there is a corresponding executable file (as can be seen in Figure 4.16). By default the “Automatically fill in Device ID” box is checked, which will automatically create a device ID label for each EasyEXPERT test record to keep track of which test or tests are associated with which die on the wafer. In addition, you can select a “Repeat Stop Condition” if the “Procedure return condition” is checked then the testing will continue until the wafer map reaches the last die; if the “Counter reaching to:” condition is checked then the testing will continue until the specified number of die have been tested. If both conditions are checked then testing will stop at whichever condition is reached first. After filling in the above information, simply click on the “Run” button to begin coordinated testing of the B1500A and your semi-automatic wafer prober.

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