Modern VNA Test Solutions Improve On-Wafer Measurement Efficiency

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Overview

Semiconductor manufacturing test engineers face increased challenges today related to broadband millimeter wave (MMW) on-wafer testing. Developing accurate models often requires measuring frequencies that range from near DC up to 100+ GHz. While in the past the need for higher frequencies was based on the need to capture harmonic content, today there are many millimeter wave applications driving on-wafer testing to frequencies exceeding 100 GHz.

Achieving accurate, stable measurements over extended time periods is a challenge for foundries and for fab-less semiconductor companies that require extensive testing of on-wafer devices. These measurements are typically performed using a vector network analyzer (VNA). In order to ensure accurate measurements, VNA re-calibration has often been required as frequently as every hour. This consumes valuable test time and during production reduces throughput. In this white paper we look at the impact of calibration downtime during on-wafer testing and discuss how recent advances enable longer time periods between calibrations.

The Impact of Frequent Test System Calibration

Semiconductor manufacturers characterize and test transistors, such as those used for power amplifiers, as well as more complicated integrated systems. Figure 1 shows their typical stages of development: device characterization, the evaluation, and the production test stage. The effects of frequent calibration to maintain accurate measurements are discussed for each phase.

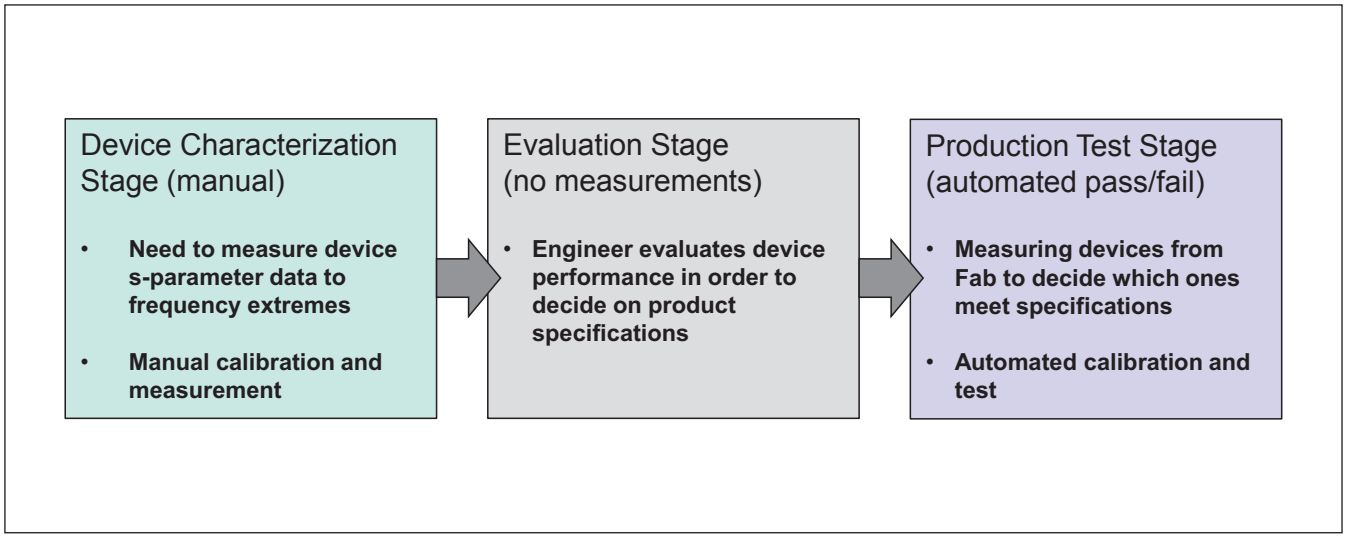

Figure 1. *Accurate, stable measurements at millimeter wave frequencies are critically important across each stage of the semiconductor manufacturing process.*

During the initial Device Characterization Stage, a primary data collection set is required for "first wafers" to help determine the specifications for the future product. Test engineers measure full s-parameter data on multiple devices across a broad frequency range at multiple bias conditions, power levels, and in some cases temperatures. These measurements are often more manual in nature, physically moving the probes around the wafer. It is important that any variation from device to device across the wafer can be accurately determined and not be caused by test equipment drift. Hence there is a need to ensure that the VNA system is correctly calibrated at intervals frequent enough to ensure consistent measurements. The manual nature of measurement during this phase also impacts the calibration as well as the need to spend time dealing with probe contact issues such as oxidation. While in some cases the calibration standards can be included on the wafer for easier calibration, the space these take up on the wafer, most often means using a separate calibration substrate; this further adds to the time required for calibration. In this situation, it is possible to have to perform a 20 minute calibration every hour. In these cases, calibration alone can consume almost one third of the test engineer's time during the device characterization stage!

The evaluation stage uses all of the device characterization data to evaluate the performance of the devices and determine the product specifications. While measurement and calibration time are not a big factor during this stage, confidence in the device characterization data plays a critical role. Accurate measurements allow for smaller measurement uncertainties which can then be used to confidently make tradeoffs between tighter specifications and manufacturing yields. Tighter specs allow for products to be better positioned in today's highly competitive marketplace.

High volume automated test equipment is used in the Production Test stage and reduced data sets are collected to verify the devices are meeting their set specifications. It is not uncommon for devices to be tested in a matter of seconds. Calibration is also part of the automated process as well. During automated production testing, calibration time is reduced, but may still be required every hour. With devices being measured every few seconds, time lost to calibration can be even more critical!

Advances in VNA Performance

For years, broadband VNA systems used large test heads, built from a combination of waveguide and coaxial components. While offering a practical way to get to frequencies up to 110 GHz, they had a tendency to be less stable and have reduced performance. Today, modern solutions are available using integrated MMIC technologies which result in more stable and better performing test solutions. The compact nature of the test heads allow for them to be more easily mounted on to the probe station and in some cases directly to the probe itself (Figure 2).

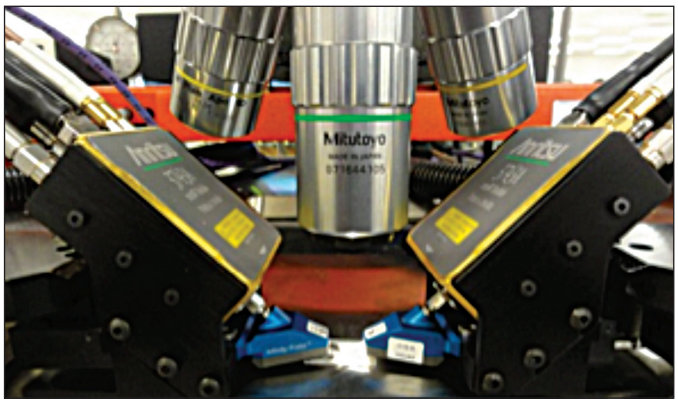

Figure 2. *Modern broadband VNA test heads are compact and offer a more accurate and stable measurement solution.*

Today's broadband VNAs are more accurate, provide more stable test solutions and offer several new capabilities:

- Single sweep broadband frequencies ranging from 40 kHz to 125 GHz
- Dynamic range of 107 dB at 110 GHz
- Positive raw directivity resulting in enhanced measurement stability and hence reduced calibration frequency
- Real-time power level control for more accurate linear gain and 1 dB compression measurements
- Compact, lightweight mm-wave modules for easy, precise, and economical positioning on the wafer probe station

Improving Measurement Efficiency

Today's broadband VNA test solutions offer better measurement stability (Figure 3) and accuracy. This allows semiconductor test engineers to perform less frequent calibrations and improve device measurement efficiency.

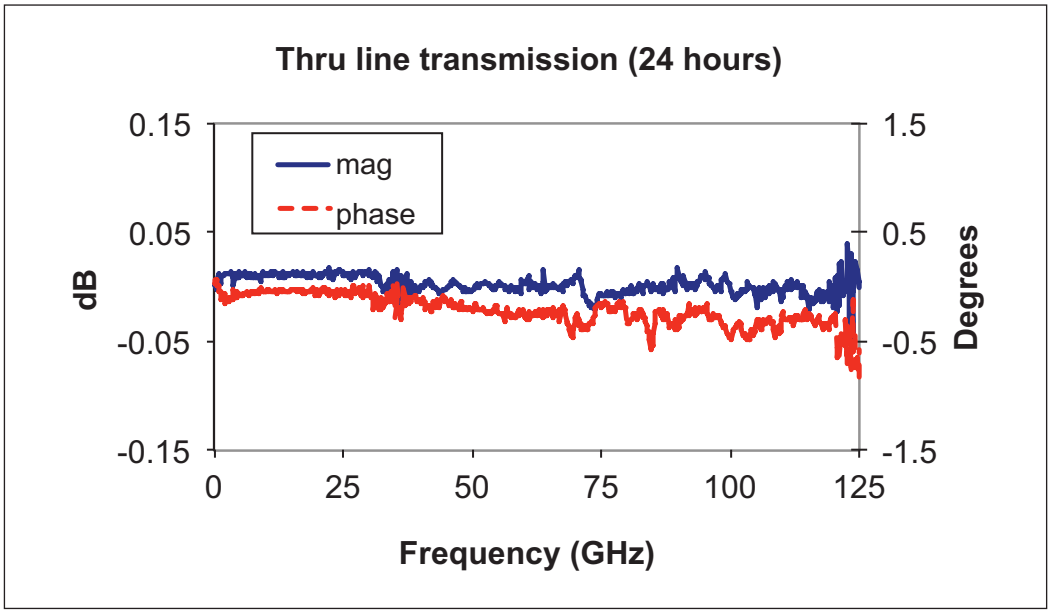

Figure 3. *Magnitude and phase stabilities achievable with new solutions (24 hours after calibration).*

During the device characterization stage, measurements are often performed in 4 hour sessions. In the past, a 20 minute calibration would be required each hour. Advances in the performance of broadband millimeter wave VNAs now offer better stability and accuracy, which allows for a single calibration to be performed once a session or even once a day. During the characterization phase of the device this represents an increase in measurement test time of over 37% in a single four hour session! Table 1 highlights the calibration efficiencies gained during the device characterization stage.

	1 Calibration per Hour (x4)	1 Calibration 4 Hour Session
Cal Time (min)	20	20
Overall Cal Time (min)	80	20
Measurement Time (min)	160	220
Measurement Efficiency	67%	92%
Efficiency Improvement		38%

Table 1. *Improving device characterization calibration efficiency over a typical 4 hour test session.*

For the production test stage, devices are often being tested around the clock. Automated test stations and wafer handling equipment optimize the time required for evaluating each device. While many aspects are accelerated, the lesser stability of older generation millimeter wave test heads can still require hourly calibrations. While this time was kept to a minimum, calibration still represents valuable time during the day that products are not being tested. Using a modern millimeter wave VNAs, calibrating a single time each day represents an increase of 8% product test time. Table 2 highlights this improvement and includes an example that shows how a test station with a 3 second DUT test time could evaluate an extra 700 devices per day! For a device with a longer test time, perhaps 10 seconds/device, the number of additional parts due to the reduced calibration frequency would be 210, however in that situation they would probably be more complex and hence more expensive devices.

	1 Calibration per Hour (x8)	1 Calibration 8 Hour Session
Cal Time (min)	5	5
Overall Cal Time (min)	40	5
Measurement Time (min)	440	475
Measurement Efficiency	91.7%	99.0%
Efficiency Improvement		8.0%
Added # of parts tested per day (assuming 3 sec/part)		700

Table 2. *Improving production test calibration efficiency over a typical 8 hour test day.*

Conclusion

Modern VNAs test solutions enable semiconductor test engineers to achieve accurate, stable measurements over extended time periods. The improvement in measurement efficiency allows them to better characterize devices in the development phase, more confidently set product specifications and test more products during production.

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