

S-PARAMETER VECTOR ERROR CORRECTION

Abstract

This application note introduces high frequency (>1GHz) S-Parameter vector error correction techniques that can be accomplished using Micromanipulator's complete line of high frequency probing products and a vector network analyzer (VNA). This Application Note opens with a brief discussion of measurement system components followed by a discussion of the main sources of high frequency measurement error. The discussion then compares two types of error correction, response and vector. Additional topics of discussion include basic-error correction choices and single port versus two port error correction. Also discussed are standard characteristics for short, open, load and thru calibration standards. The application note closes with a brief description of the equipment recommended to perform error correction measurements. This application note assumes the reader is familiar with S-Parameter measurements and network analyzer operation.

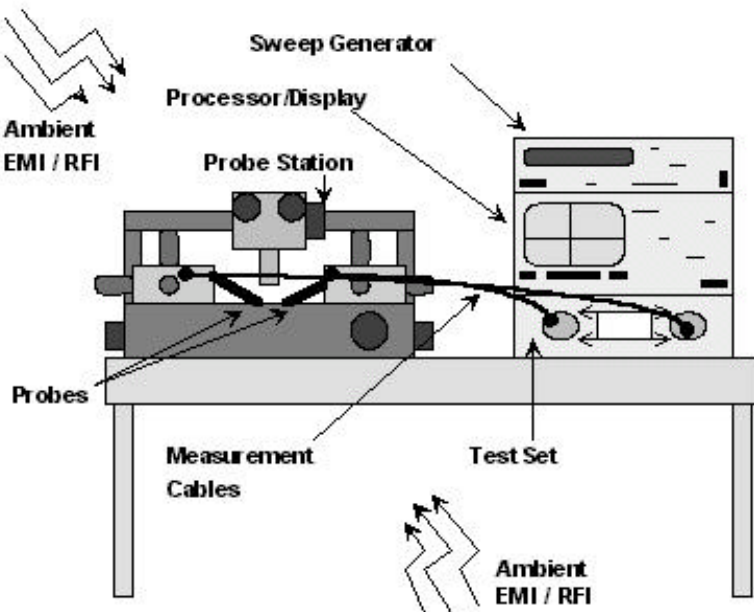
The complete measurement system

The illustration below shows a typical 2-port wafer level high frequency measurement system. A complete wafer measurement system consists of:

- Probe Station
- Measurement Probes
- Measurement Cables
- Sweep Generator
- Processor/ Display

- Test Set(s)
- Ambient Environment

The entire measurement system can adversely effect the accuracy and reliability of error correction measurements. Engineers must not only be aware of the effects of the measurement system, but must also become familiar with the different methods used to negate their effects.



Sources of Error

When making high frequency error correction measurements, Engineers are concerned with three different categories of measurement error. These are systematic errors, random errors and drift errors. Each type of measurement error has its own unique "signature" and source.

Systematic Errors: Systematic errors are due to imperfections in the entire measurement system. As shown in the previous section, the measurement system consists of the ambient environment, the probe station, the probes, sweep generator, test set(s), processor/display and the measurement cables. The effects of systematic errors are predictable in behavior and can be removed using a variety of error correction techniques and proper probing equipment design.

Random Errors: Random errors are more troublesome than systematic errors. This is due in part because they are unpredictable and very sporadic in nature. Perhaps, however, the biggest problem with random error is rooted in the fact that they can not be compensated for. As a result, measurement equipment considerations become key because Engineers do not want equipment that will result in substantial phase, ambient, physical vibration, or switching noise, from devices such as drive motors, or drive electronics.



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Drift Errors: Drift errors are due to changes in the measurement environment that occur after error correction is performed. Drift errors can be caused by changes in temperature or instability. For this reason, it is important to consider the overall stability of your entire measurement system. If your measurement system is not stable, frequent and time consuming error correction measurements will be required.

Types of Error Correction

Engineers have two main types of error correction to choose from: *Response* and *Vector*. Response, or normalization error correction measurements are simple to perform, but only correct for tracking errors. For many applications, simply correcting for tracking errors is not sufficient. Therefore, many Engineers use vector error correction, which is the main focus of this Application Note. Vector error correction measures known calibration standards. The known standards measured include open, short, load and thru. Vector error correction is superior in comparison to normalization because it compensates for all major sources of systematic error.

Vector Error Correction Choices

Engineers have several choices and considerations to make when choosing a vector error correction method. The goal is to remove the systematic effects of the measurement system, recognizing that selection of the proper probing equipment can mitigate random and drift error.

There are four basic categories of error correction; uncorrected, response, single port and full two port. Each method has advantages and disadvantages.

Uncorrected

Rarely used, the main advantage of uncorrected error measurements is convenience and speed. When using uncorrected error correction, the engineer is not concerned with removing any systematic errors from the measurement system. The disadvantage of uncorrected calibration is that the measurement system can significantly impact measurements and render some data useless. As measurement frequency and device performance demands increase, the usefulness of uncorrected error correction is significantly diminished.

Response

This type of systematic error correction removes frequency response error and requires only a thru standard. The main advantage of response measurements is that they are easy to perform. Very little operator skill in using the calibration features of various VNA's is required. Engineers typically choose response measurements when the highest level of calibration accuracy is not required by their application.

Single Port

Single port error correction removes directivity, source match and reflection tracking errors. Short, open and load standards are necessary for single port corrections. This method of error correction is more accurate than response correction, but is somewhat more difficult to perform. In order to perform this type of error correction, good connector termination, impedance match and precise probe placement and design become critical.

Full Two Port

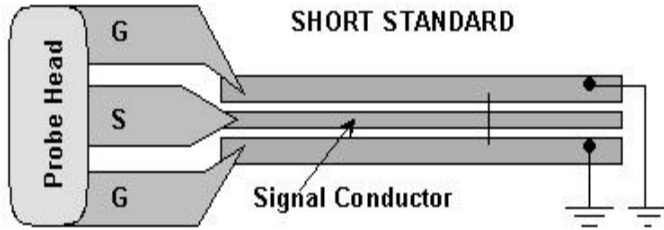
Full two port system error correction is the most accurate of all correction methods, but also the most difficult. Full two port correction can remove directivity, source, load match, reflection tracking, transmission tracking and crosstalk. Open, short, thru and load standards are necessary for full two port error correction. In order to perform this type of error correction, good connector termination, impedance match and precise probe placement are most critical.

Standard Characteristics

When performing vector error correction, there are four standards available to the engineer: Short, Open, Load and Thru. As discussed in the previous section, depending on the error correction being performed, different devices will be used.

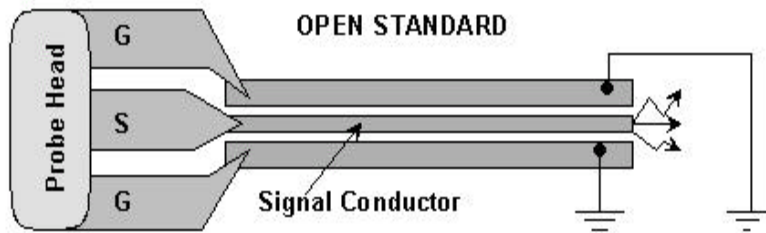
Short Standard – Used for single and two port error correction.

A short standard in an ideal situation will have unity reflection with 180 degrees of phase shift. An ideal short will reflect 100% of the incident source energy back to the reference, but will be 180 degrees out of phase from the reference. Many short calibration standards, like the ones offered by Micromanipulator, tie a single conductor directly to a reference ground. Short standards offered by Micromanipulator also keep the short length to a minimum to reduce excess inductance and reduce the need for calibrated offset lengths. A typical short standard and response are shown below.



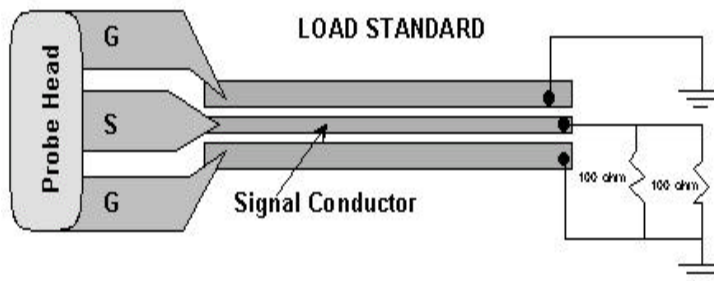
Open Standard - Used for single and two port error correction.

A perfectly unterminated transmission line represents an ideal open calibration standard. An open should exhibit unity reflection with no phase shift. All of the incident energy should be reflected to the reference and will be in phase with the reference signal. A typical open standard and calibration response are illustrated below.



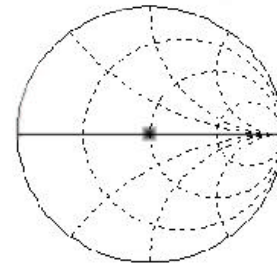
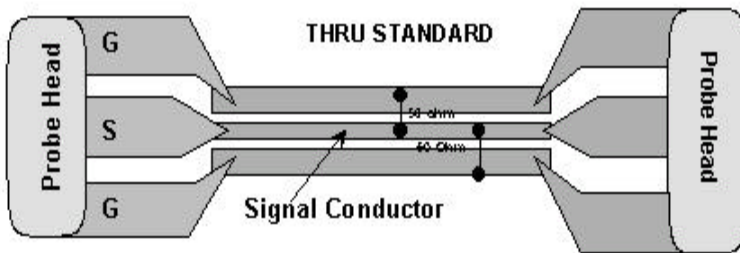
Load Standard - Used for single and two port error correction.

An ideal load standard provides a perfect termination and therefore reflects none of the incident signal. In reality, some reflection will always exist, but high accuracy calibration standards like those supplied by Micromanipulator represent near ideal characteristics over very wide frequency ranges. As illustrated in the diagram, a load standard is nothing more than a parallel resistive load. Typically, two 100 ohm resistors will be placed in parallel to represent a 50 ohm load.



Thru Standard - Used for single, two port and response error correction.

A thru is nothing more than a simple transmission line. Calibration standards, like those supplied by Micromanipulator, have thru devices with constant impedance (typically 50 ohm) and negligible mismatch at both standard ends to reduce reflection and loss. The response shown is for a thru terminated with Z_0 .



Equipment

The following components make up a complete probing system to support accurate S-Parameter vector error correction.

Calibration standards: Calibration standards are essential to error correction. Most calibration standards have precise short, open, load and thru standards.

For complete capability, calibration standards should include:

- Convenient alignment of open, short, matched load and thru devices
- Support of probe pitch ranges from 30 to 1,250 microns
- Support of frequency ranges from DC to 220GHz
- Support of GS, SG and GSG footprint configurations

Calibration substrate holder chucks: A calibration substrate holder chuck is designed to simultaneously hold the DUT and the calibration standard. This makes error correction easy, efficient and accurate. Calibration chucks are ideal for removing systematic errors and can reduce the amount of time needed to compensate for drift errors. Ambient and thermal chucks are available.

Stable Z-axis chuck drives: For high frequency measurements, a Z-chuck is essential. Motion in the Z-axis insures that the reference plane of error correction measurements matches the reference plane of the DUT. This is a key consideration to insure maximum error correction accuracy and stability.

Stable probe positioners: Engineers familiar with the error correction techniques appreciate the need for stable probe positioners. The best efficiency is realized with positioners with five axis of motion, including probe tip theta and planarity adjustments. Vacuum, magnetic, magnetic assisted vacuum and mechanical locking bases are available for maximum stability and flexibility during error correction measurements.

High frequency probes and cables:

For best results, high frequency probes and cables must have massive mounts to reduce vibration, extremely low insertion loss values and outstanding measurement repeatability and return loss.

Picoprobes™, for example, feature Beryllium-Copper (BeCu) probe tips that are individually spring loaded to provide consistent and repeatable DUT and calibration substrate contact, even when probing non-planar surfaces. Picoprobes are available with almost any pitch and footprint configuration and use a patented coaxial design that further reduces cross talk and other sources of microwave measurement errors. In addition, professionals will appreciate being able to view the probe tips when touching down. Some industry probes make probe tip viewing difficult, if not impossible, increasing the possibility of costly probe damage.

Summary

This Application Note has discussed high frequency (>1GHz) S-parameter vector error correction techniques that can be made using Micromanipulator's probing equipment and a vector network analyzer. The Application Note discussed measurement system components, sources of error, error correction choices, single port versus two port error correction and characteristics of short, open, load and thru calibration standards.