SAND2011-2357C

Why do we calibrate?

- Actually we don’t: calibration of analyzers is done before each measurement with a calibration kit supplied by the manufacturer (usually) for each connector type

- We quantify the residual error leftover due to: mathematical imperfection in the calibration model for a given calibration kit, connector repeatability, cable and adaptor effects, noise.

Why can’t I just use a “calibrated” calibration kit?

- Hard to come by, although the eCal units from Agilent can come with accredited calibrations.

- Uncertainties over the full measurement space is still not quantified. A lot of math. A complex model, and Monte Carlo is required to do this.

Physical Calibration Challenges

- Regular calibration required due to temperature changes
- Microwave connectors in calibration kits as well as port connections subject to wear and damage
- Effects form cables, connectors and adaptors
- Highly sensitive to operator error

Mathematical Calibration Challenges

- 8 error terms over a broad frequency range
- Equations for error terms are complex and non-linear
- Limited standards available: large range of points calculated for limited number of input variables
- Mathematics is complex; alphabet soup of calibration methods to choose from, each requiring a specific set of standards
- Uncertainty of standards can only be incorporated using Monte Carlo techniques

What does the Sandia PSL currently offer?

- Quantification of measurement uncertainty for a given VNA using TMS (low frequency) and TRL (high frequency) for a given VNA/calibration kit/cable combination
- Only special cases: Sii (Sij=0) or Sij(Sii=0)
- Select Agilent models only

What does the Sandia PSL currently NOT offer?

- Full correction matrices for use across the full measurement space.
- Support for all Agilent models (or for any other manufacturer)
- Evaluation of measurement uncertainty for the customer's specific measurement which depends on
  - Environment
  - Adaptors
  - VNA setup: averaging, BW etc.
  - Specific frequency and scattering parameter value

Goal of improvements

- Separate data collection from data analysis so that all analyzers can be supported
- Provide (or apply) full corrections (not just list of uncertainties for special cases)
- Improve uncertainties
- Improve efficiency and turn-around times
- Allow flexibility in what we supply to our customers

Will require…

- New modular software:
  - Drivers for each supported model will have to be written to collect data
  - Standardized data file format so that data from any analyzer can be processed using the same SW
- New paradigm so that
  - Flexibility in standard set used
  - Improved uncertainties
  - Provide DUT corrections or full correction matrix to enable more precise DUT calibrations

NIST developed SW and tools Veridical

- Provides calibration verification through calibrated eCal units and NIST supplied SW
- Data analyzed and recorded remotely through internet
- Only 2.4 and 2.92 connector types currently supported
- Only verification: DUT correction matrix not supplied

The Challenge…

- We require quantification of uncertainties and confidence intervals, not just a “verification” that the analyzer is “working”.
- Flexibility and faster turn-around time
- We must have way to incorporate the uncertainties of our standards as well as from cables and connectors, and calibration kit degradation.

The Plan

- Implement a NIST developed software package: StatisiCAL
- Uses a non-linear least squares method (ODR) to compute error terms as well as 95% confidence intervals

Advantage of StatistiCal

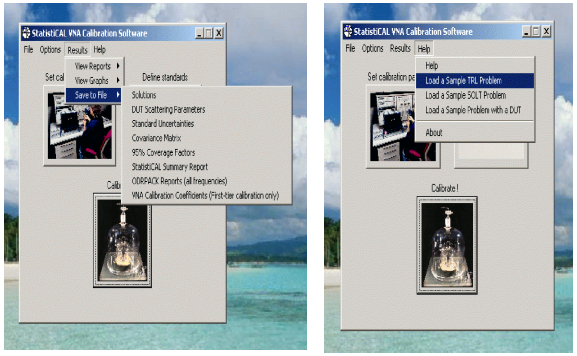
- Data can be ported to be analyzed on any computer (separate from the specific analyzer and data acquisition)
- Simple data format requirement
- Gets away from fixed standard sets (TMS, TRL etc.). You can mix-and-match standards for your application
- Calculates 95% confidence intervals
- Calculates uncertainty for the DUT measurement allowing time-of-test measurements for N-port measurements.

StatistiCAL Vector-Network-Analyzer Calibration Software

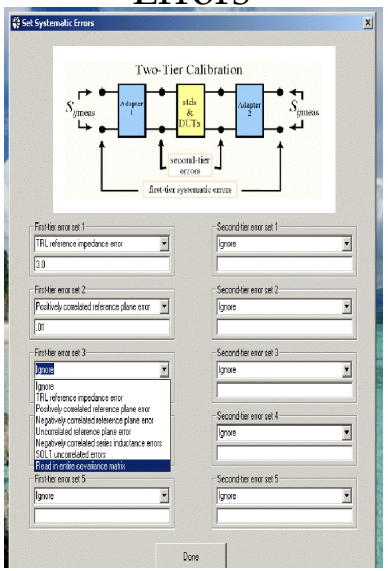
Dylan Williams, C.M. Wang, and Uwe Arz

We have developed a new freeware package for calibrating vector network analyzers (VNAs). The software accommodates almost all coaxial and on-wafer standards, and enables a "mix and match" philosophy to VNA calibration. The software is based on an algorithm developed at the U.S. National Institute of Standards and Technology (NIST) and the Physikalisch-Technische Bundesanstalt (PTB) of Germany, which is able to estimate the uncertainty of its own results due to random errors. The algorithm features a high degree of robustness, allowing it to find solutions even with poor initial estimates.

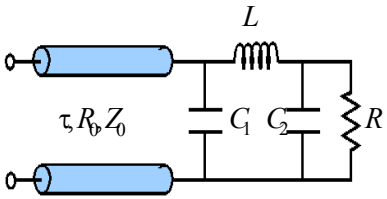
Solutions, Uncertainties, and More



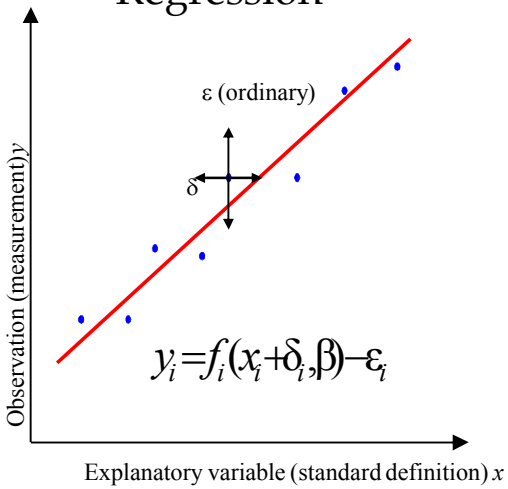
Systematic Errors

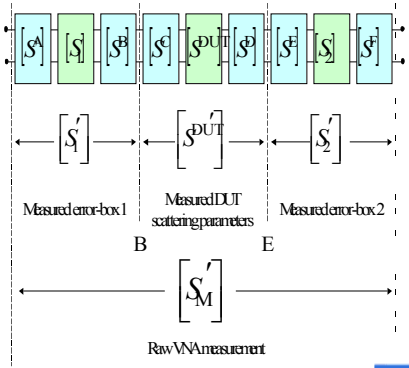


Flexible Calibration Models



Orthogonal Distance Regression





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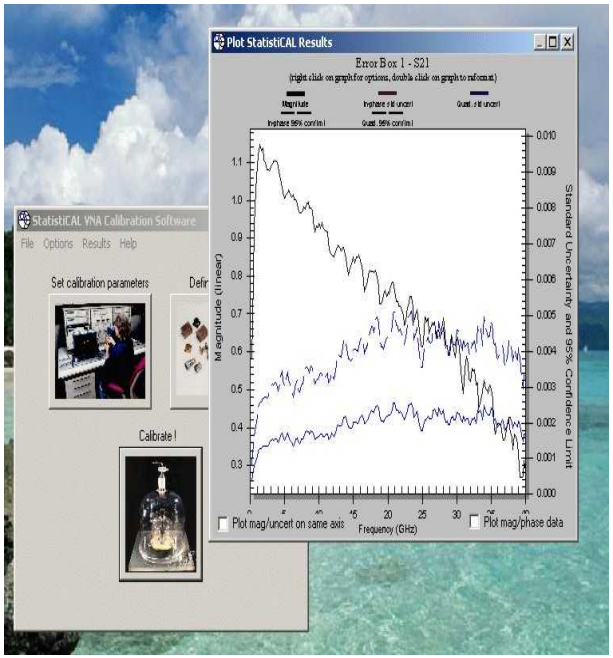
StatistiCAL Vector-Network-Analyzer Calibration Software

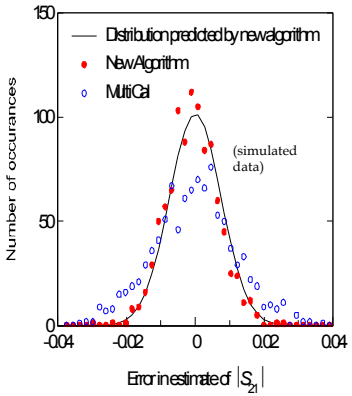
Dylan Williams, C.M. Wang, and Uwe Arz

StatistiCAL Advantages

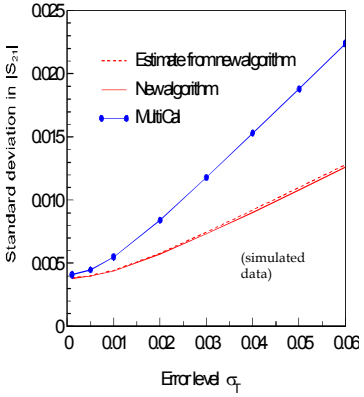
- Mix and match calibration standards
- Improve accuracy with redundant measurements
- Estimate uncertainty automatically



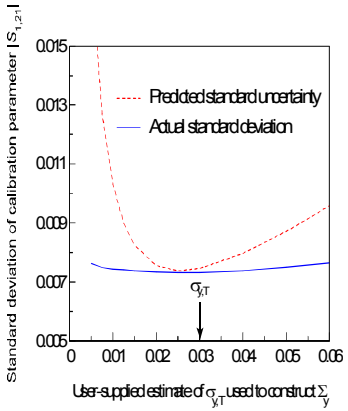
Greater Accuracy



Reliable Uncertainties



Solution Refinement



This software combines a decade of experience in statistics and orthogonal distance regression with an easy-to-use user interface. Research at NIST has extended the analysis of uncertainties to include systematic errors in the solution. The uncertainties in the solution are represented by a covariance matrix that relates errors in both the VNA calibration and measurements of the device under test. In addition, the algorithm determines coverage factors based on the different numbers of degrees of freedom associated with various parts of the solution.

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How to use it

- Get standard definition files for a set of standards of your choice (these can be numerical Sij, or models. Setup StatistiCAL with standard set that you plan to run.
- Take data at frequencies of interest and store in StatistiCAL format (using a data acquisition method of YOUR choice).
- Port the data and model files to the computer running StatistiCAL. Let it grind…
- Out comes the error matrix and confidence intervals.

Some caveats

- Uncertainties in the standard definition have to be handled separately: this can be done using a Monte Carlo distribution of standard definition files.

Further into the future

- NIST has supplied me with a beta version of an uncertainty analyzer that can be used with StatistiCAL to compute the errors due to *user defined* models for adaptors.
- Things like refined definitions for things like airline models can be incorporated.
- Calculates sensitivity coefficients
- Uncertainty Analyzer will eliminate the need for multiple standard definitions in StatistiCAL to incorporate uncertainties in standard definitions.