

VNA Tools II

S-parameter uncertainty calculation

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Outline

Introduction

VNA Measurement Model

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Introduction

Problem

Computation of the uncertainties of S-parameter measurements.

Solution

Set up a measurement model for the Vector Network Analyzer and propagate all uncertainties through the VNA measurement model.

Measurement Errors

Which non correctable influences affect the S-parameter measurements?

- ▶ Noise floor and trace noise
- ▶ Linearity
- ▶ Drift of switch and calibration error terms
- ▶ Cable stability
- ▶ Connector repeatability
- ▶ Calibration standard definitions

VNA Measurement Model

The following equation describes the in VNA Tools II used N -port VNA measurement model. All bold variables are S-parameter matrices and i is the measurement index.

$$\mathbf{M}^{(i)} = \mathbf{R}^{(i)} + \left[\left(\mathbf{W} + \mathbf{V}^{(i)} \right) \oplus \left[\left(\mathbf{E} + \mathbf{D}^{(i)} \right) \oplus \left[\mathbf{C}^{(i)} \oplus \mathbf{S}^{(i)} \right] \right] \right]$$

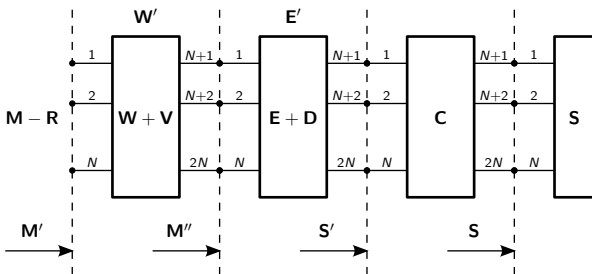


Figure: VNA Measurement Model

VNA Measurement Model - Raw Data

- M** denotes the raw data measured by the VNA.
It changes from measurement to measurement.
- R** denotes the noise and linearity influences.
It changes from measurement to measurement.

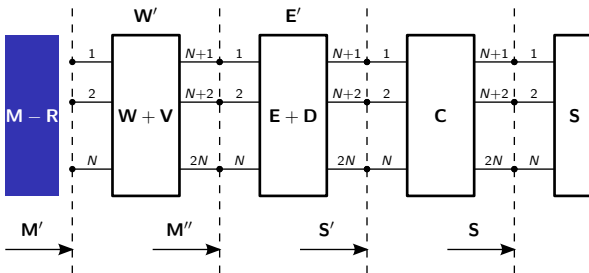


Figure: VNA Measurement Model

VNA Measurement Model - Calibration Error Terms

- E** denotes the calibration error terms.
It's constant during an entire calibration.
- D** denotes the drift of the calibration error terms.
It changes from measurement to measurement.

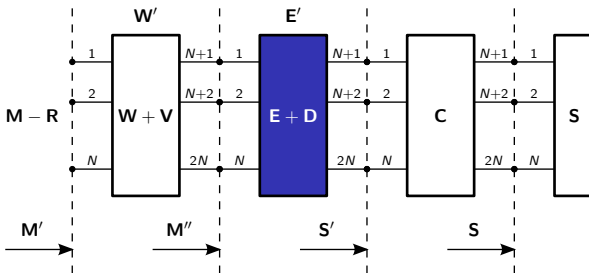


Figure: VNA Measurement Model

VNA Measurement Model - Cable and Connector

C denotes the cable stability and connector repeatability influences. It changes for every new connection or cable movement.

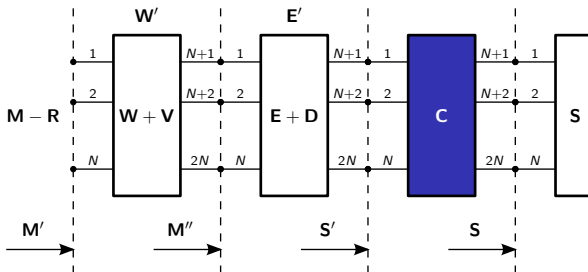


Figure: VNA Measurement Model

VNA Measurement Model - Error Corrected Data

S denotes the error corrected data or the calibration kit standard definitions. It changes if a new device is connected.

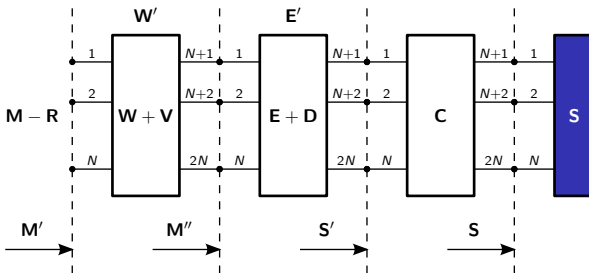


Figure: VNA Measurement Model

Uncertainty

- ▶ There are four groups of uncertainty influences:
 1. Noise and Linearity
 2. Drift of Switch and Error Terms
 3. Cable and Connector
 4. Calibration Standard
- ▶ All influences are frequency dependent.
- ▶ All influences are either correlated or uncorrelated.
- ▶ Uncertainty influences are represented by Metas.UncLib objects.

Uncertainty - Metas.UncLib

Metas.UncLib is a measurement uncertainty calculator.

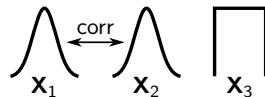
The user specifies

- ▶ input quantities \mathbf{X} with input covariance matrix \mathbf{V}_X
- ▶ measurement model \mathbf{f}

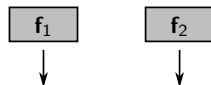
Metas.UncLib computes

- ▶ output quantities $\mathbf{Y} = \mathbf{f}(\mathbf{X})$
- ▶ Jacobi matrix \mathbf{J}_{YX} of \mathbf{f} using automatic differentiation
- ▶ output covariance matrix $\mathbf{V}_Y = \mathbf{J}_{YX} \mathbf{V}_X \mathbf{J}_{YX}'$

Input quantities



Measurement model



Output quantities

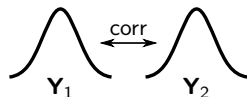


Figure: Metas.UncLib

Uncertainty - Noise and Linearity

Noise

- ▶ Uncorrelated for each measurement.
- ▶ Depends on the VNA device noise floor and trace noise definition.

Linearity

- ▶ Correlated for each measurement.
- ▶ Depends on the VNA device linearity definition.

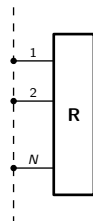


Figure: Noise and linearity in the VNA measurement model

Uncertainty - Drift of Switch and Error Terms

Drift

- ▶ Uncorrelated for each measurement.
- ▶ Depends on the VNA device switch term, directivity, tracking, match and isolation drift definition.

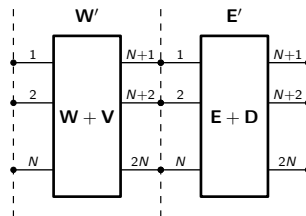


Figure: Drift of switch and error terms in the VNA measurement model

Uncertainty - Cable and Connector

Cable

- ▶ Uncorrelated for each new cable position.
- ▶ Depends on the cable stability definition.

Connector

- ▶ Uncorrelated for each new connection.
- ▶ Depends on the connector repeatability definition.

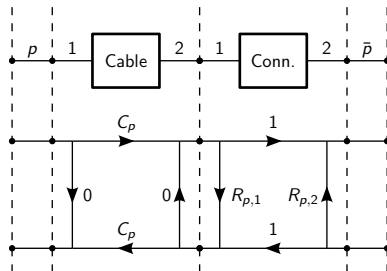


Figure: Cable stability and connector repeatability 2-port for one port in the VNA measurement model

Uncertainty - Calibration Standard

Agilent Model Standard

- ▶ Open and Short have specified Phase Deviation in deg. Magnitude deviation assumed to be the same as the phase deviation.
- ▶ Load has specified Return Loss in dB.

Databased Standard

- ▶ Uncertainties explicitly stated for each data point.

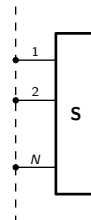


Figure: Calibration standard definition in the VNA measurement model

Uncertainty - Propagation

- ▶ The uncertainty influences are defined by **R**, **V**, **D**, **C** and **S**.
- ▶ VNA measurement model:

$$\mathbf{M}^{(i)} = \mathbf{R}^{(i)} + \left[\left(\mathbf{W} + \mathbf{V}^{(i)} \right) \oplus \left[\left(\mathbf{E} + \mathbf{D}^{(i)} \right) \oplus \left[\mathbf{C}^{(i)} \oplus \mathbf{S}^{(i)} \right] \right] \right]$$

- ▶ Calibration and error correction are based on the above equation.
- ▶ Linear uncertainty propagation is done with Metas.UncLib.
- ▶ The complexity is hidden from the user and from the VNA Tools II programmer.
- ▶ Metas.UncLib takes care about correlations.

Visualization

VNA Tools II supports different view modes:

Graph shows a graphical visualization of multiple files.

Table shows a tabular visualization of a single file.

Point shows an uncertainty budget for one frequency point and one parameter of a single file.

There are three different uncertainty modes:

None hides the uncertainty.

Standard shows the standard uncertainty (67% coverage factor, $k = 1$).

U95 shows the expanded uncertainty (95% coverage factor, $k = 2$).

Visualization - Graph

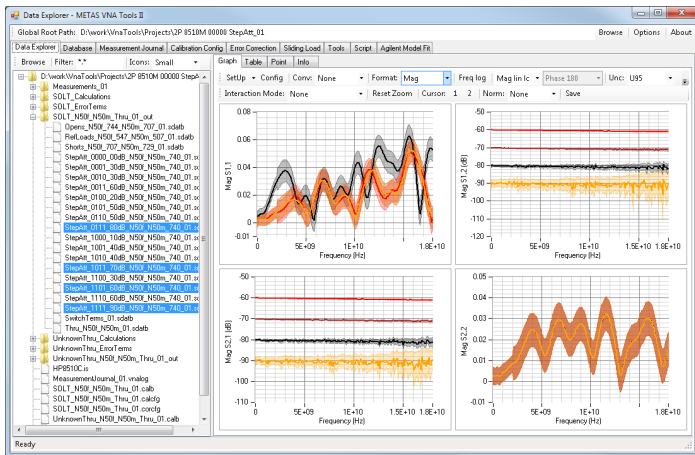


Figure: Data Explorer Graph

Visualization - Table

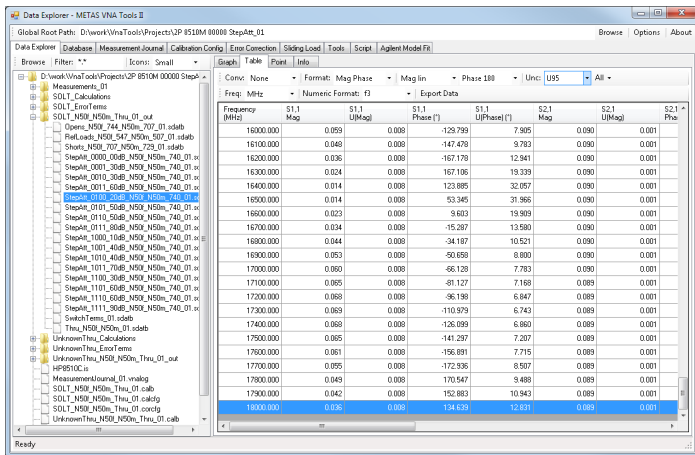


Figure: Data Explorer Table

Visualization - Point

Global Root Path: D:\work\VnaTools\Projects\2P 8510M 00000 StepAtt_01

Database Measurement Journal Calibration Config Error Correction Sliding Load Tools Script Agilent Model File

Graph Table Point Info

Freq: 18.000e+09 Hz First Last Parameter: S2,1 Conv: None Format: Mag Id

Value Std Unc U95
0.089164956 0.000454327 0.000909654

Influence	Info	Port	Index	Plat	Unc Component	Unc [%]
Cable	Position: 2	Port: 2	Freq 190	Mag	0.000307965	45.027
Cable	Position: 1	Port: 2	Freq 190	Mag	0.000306932	45.490
VNA Drift Tracking	Measurement: 10	Port: 2	Freq 190	Mag	0.000074556	2.686
VNA Drift Tracking	Measurement: 4	Port: 2	Freq 190	Mag	0.000074433	2.677
Cal Std Open	Type N (50) female open			Phase	0.000039254	0.745
Agilent Unc CTTI File	Type N (50) male load SN:00507	S1,1	Freq 229	Imag	0.000034330	0.569
VNA Trace Noise	Measurement: 10	S2,1	Freq 190	Mag	0.000029035	0.407
VNA Trace Noise	Measurement: 4	S2,1	Freq 190	Mag	0.000029033	0.407
Cal Std Short	Type N (50) female short			Phase	0.000027982	0.376
Cal Std Open	Type N (50) female open			Mag	0.000015966	0.123
Agilent Unc CTTI File	Type N (50) male load SN:00507	S1,1	Freq 229	Real	0.000015370	0.114
Agilent Unc CTTI File	Type N (50) female load SN:00547	S1,1	Freq 229	Imag	0.000014655	0.104
VNA Drift Tracking	Measurement: 4	Port: 2	Freq 190	Phase	0.000013682	0.093
VNA Drift Tracking	Measurement: 10	Port: 2	Freq 190	Phase	0.000013690	0.091
VNA Linearity	@ -100 dB	Port: 2	Freq 190	Mag	0.000013163	0.084
Cal Std Short	Type N (50) female short			Mag	0.000008214	0.041
VNA Noise Floor	Measurement: 3	S2,1	Freq 190	Real	0.000007907	0.029
VNA Noise Floor	Measurement: 10	S2,1	Freq 190	Real	0.000007120	0.024
Agilent Unc CTTI File	Type N (50) female load SN:00547	S1,1	Freq 229	Real	0.000006946	0.023
Cable	Position: 1	Port: 2	Freq 190	Phase	0.000005321	0.014
Connector	Connection: 4	Port: 1, R2	Freq 190	Imag	0.000004235	0.009

Ready

Figure: Data Explorer Point

Results

- ▶ New VNA measurement model for a N -port Vector Network Analyzer.
- ▶ Definition of all influences that affect the measurements.
- ▶ Linear propagation of all uncertainties through the VNA measurement model.
- ▶ Visualization of S-parameter data with uncertainties.