METAS VNA Tools - User Manual V2.9.4

Michael Wollensack

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Contents

1 Installation

1.1 System Requirements

The following list describes the minimum software and hardware requirements of METAS VNA Tools.

- Microsoft Windows 7 (64 Bit)
- Microsoft .NET Framework 4.6.2
- Microsoft Windows Installer 4.5
- National Instruments VISA 19.0, Keysight IO Libraries Suite 2023 or Rohde & Schwarz VISA 5.12.8. See appendix D.1 for more information.
- At least 1024 megabytes (MB) of RAM (4096 MB is recommended)
- At least 200 megabytes (MB) of available space on the hard disk (10 GB is recommended)
- Video adapter and monitor with SVGA (800 x 600) or higher resolution (1920 x 1200 is recommended)

1.2 Steps

The following steps describe the installation of METAS VNA Tools.

1. Double-click on the METAS VNA Tools setup program
2. Accept license agreement
3. Select installation folder
4. Confirm installation
5. Installation complete

After the installation, one can start METAS VNA Tools by double-clicking on its desktop shortcut.

2 Overview

METAS VNA Tools is a software which is designed to compute uncertainties of S-parameter measurements:

- It uses a VNA measurement model for N-port Vector Network Analyzers.
- It supports the following calibration types: One Port, SOLT, GSOLT, QSOLT, Unknown Thru, TRL, LRRM, Juroshek, Reflection Normalization, Transmission Normalization, One Path Two Ports, LHKM (TRL, LRL, TRM, LRM), Frequency Conversion Scalar Mixer, Frequency Conversion Unknown Mixer and Optimization.
- It allows the definition of all influences that affect VNA measurements.
- It uses the Linear Propagation module of METAS UncLib to propagate all uncertainties through the VNA measurement model.
- It can visualize S-parameter data with uncertainties.

The graphical user interface is split up into two parts, see figure 1. The navigation bar is in the upper part of the screen and below is the tabular control.

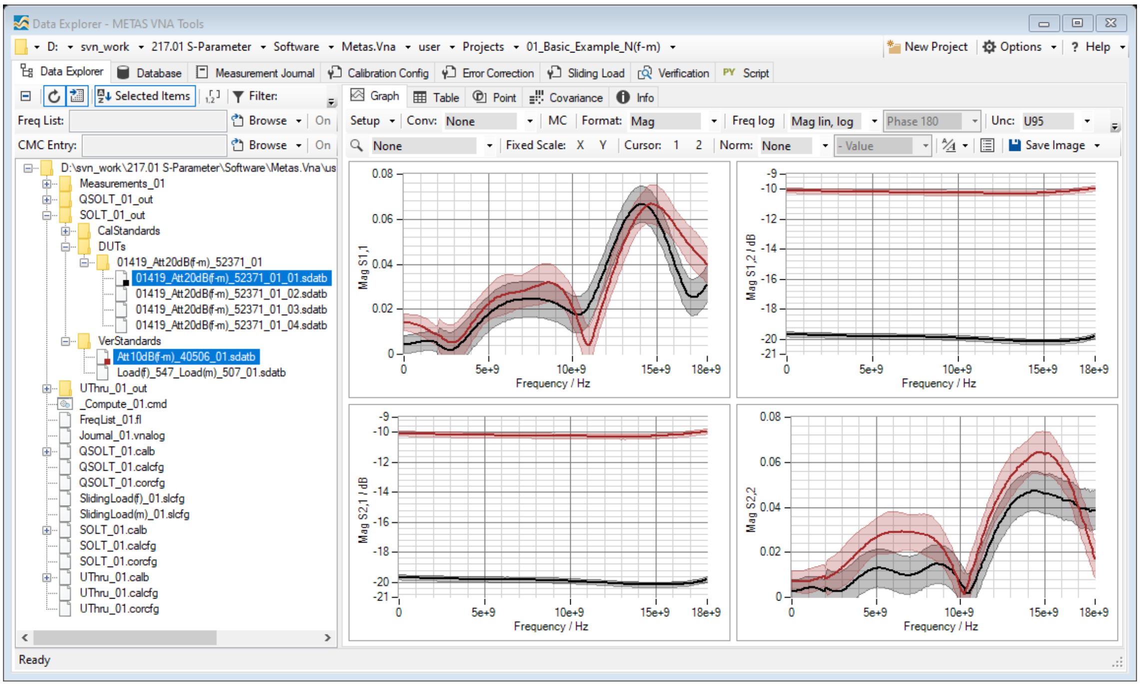

Figure 1: METAS VNA Tools

2.1 Navigation Bar

The following user controls are available in the navigation bar:

Root Path sets the root directory for all tabular pages.

New Project creates a new project (shortcut: Ctrl + Shift + N), see section 2.1.1.

Options sets the METAS VNA Tools options (shortcut: Ctrl + Shift + O), see section 2.1.2.

Console shows or hides the console window (shortcut: Ctrl + F11).

Split View splits the tabular control (shortcut: Ctrl + F12).

Reset Window Layout resets the window layout.

Create Screenshots creates screen shots of all tabular pages.

Help contains the following items:

- User Manual
- Math Reference
- Data Formats
- Programming Reference
- Website
- Forum
- License
- About

2.1.1 New Project

The dialog called New Project can be used to create a new project, see figure 2. The following

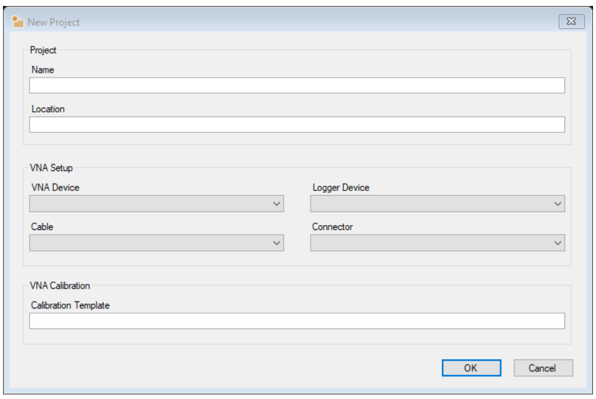

Figure 2: METAS VNA Tools / New Project

user controls are available:

Project Name specifies a name for the new project. A new directory will be created.

Project Location sets the root directory for the new project.

VNA Device selects a VNA device.

Logger Device selects a logger device.

Cable selects a cable from the database.

Connector selects a connector from the database.

Calibration Template selects a template for the calibration configuration from the database.

2.1.2 Options

The options dialog can be used to configure the options of METAS VNA Tools, see figure 3. The following user controls are available:

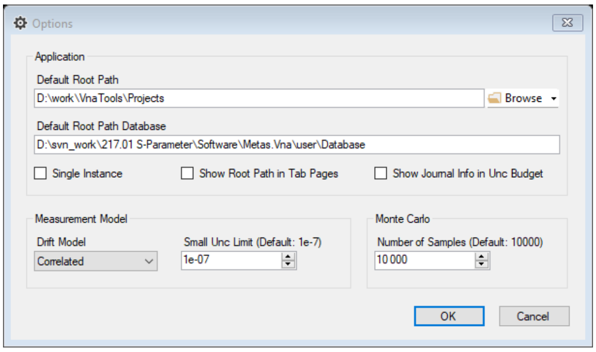

Figure 3: METAS VNA Tools / Options

Default Root Path sets the root directory.

Default Root Path Database sets the root directory for the database.

Single Instance limits the METAS VNA Tools application to one instance.

Show Root Path in Tab Pages shows or hides the root path in the configuration tabular pages.

Show Journal Info in Unc Budget shows or hides the measurement journal info in the uncertainty budget.

Drift Model specifies the used drift model. One can chose the Correlated or Uncorrelated model (default: Correlated). The uncorrelated drift model is obsolete and was used in older versions of VNA Tools (before V0.9). The correlated model uses the time stamp of the measurement to compute how big is the drift between multiple measurements.

Small Unc Limit is relative to the total uncertainty and specifies the limit below which uncertainty influences are discarded. When saving a computed result this helps to reduce file size but makes the uncertainty budget less complete (default: 1e-7).

Number of Samples specifies the number of samples used in the Monte Carlo simulation.

2.2 Tabular Control

The following tabular pages are available:

Data Explorer is designed to visualize S-parameter files (shortcut: Ctrl + F1).

Database specifies values and uncertainties of VNA devices, cables, connectors, DUTs, calibration standards, CMC entries and logger devices (shortcut: Ctrl + F2).

Measurement Journal is used to collect measurement data and to protocol the measurement process (shortcut: Ctrl + F3).

Calibration Config configures a VNA calibration and computes the error terms (shortcut: Ctrl + F4).

Error Correction configures and computes the error correction of raw measurement data (shortcut: Ctrl + F5).

Sliding Load configures and computes the circle fit of a sliding load (shortcut: Ctrl + F6).

Verification configures a VNA verification and computes the normalized error (shortcut: Ctrl + F7).

Script provides a built-in Iron Python script engine (shortcut: Ctrl + F8).

3 Data Explorer

The Data Explorer tabular page is designed to visualize S-parameter files. The graphical user interface is split up into two parts. The file explorer is on the left and the visualization with different tabs is on the right.

3.1 File Types

Table 1 shows the supported file types. S-Parameter Data files can only contain S-parameter

Table 1: File types

Description	Extension
S-Parameter Data Binary	(.sdatb)
S-Parameter Data Xml	(.sdatx)
S-Parameter Data Covariance Text	(.sdatcv)
S-Parameter Data Touchstone	(.s*p)
S-Parameter Data Touchstone V2.0	(.ts)
VNA Calibration Data Binary	(.calb)
VNA Data Binary	(.vdatb)
VNA Data Xml	(.vdatx)
VNA Data Covariance Text	(.vdatcv)
VNA Data CITI	(.cti;.citi)
S-Parameter Data Collection Binary	(.scolb)
S-Parameter Data Collection Covariance Text	(.scolcv)
VNA Data Collection Binary	(.vcolb)
VNA Data Collection Covariance Text	(.vcolcv)
ZIP with embedded data files	(.zip)
PDF with embedded data files	(.pdf)

data. In contrast VNA Data files can contain receiver values and ratios of receiver values.

3.2 File Explorer

The following user controls are available:

Collapse All collapses all tree nodes.

Auto Refresh refreshes the file explorer on the left (default: on).

Auto Update Panel updates the visualization tabs on the right (default: on).

Sort Selected Items sorts the selected items (default: on).

Ignore Port Assignment ignores the port assignment from the selected data files (default: off).

Filter sets file filter (default: *.*).

Freq List Browse can be used to select a frequency list file (*.fl). All selected files in the tree view will be interpolated (default: None).

Freq List On turns frequency list interpolation on or off (default: off).

CMC Entry Browse can be used to select a CMC entry file (*.cmc). All selected files in the tree view will be verified against the CMC entry (default: None).

CMC Entry On turns CMC verification on or off (default: off).

Tree View can be used to select one or multiple files. Additional files can be selected while holding the Ctrl or Shift key.

3.2.1 Content Menu

The content menu of the File Explorer provides some tools for post processing of data sets. All post processing tools propagate the uncertainties of the inputs to the results. The following tools are available:

Show in Windows Explorer shows a file or directory in the Windows Explorer.

Set as Root Path sets the current directory as root path.

New Folder creates a new folder in the current directory.

New Shortcut creates a new shortcut in the current directory.

Save Data As ... saves the current file in another file. Supported file formats are S-Parameter Data (*.sdatb or *.sdatx), S-Parameter Data Covariance Text (*.sdatcv), Touchstone (*.s1p, *.s2p, *.s*p), Touchstone V2.0 (*.ts), VNA Data (*.vdatb or *.vdatx), VNA Data Covariance Text (*.vdatcv) or CITI (*.cti or *.citi).

Save Collection As ... saves the current files in a collection file. Supported file formats are S-Parameter Data Collection (*.scolb), S-Parameter Data Collection Covariance Text (*.scolcv), VNA Data Collection (*.vcolb) or VNA Data Collection Covariance Text (*.vcolcv).

Frequency and Port Definitions shows the port assignment, the port reference impedance and the frequency conversion per port.

Change Port Assignment changes the port assignment and a subset can be taken[1]. The new ports can be optionally sorted in the following order: port number, port mode (s, d, c).

Change Port Zr changes the reference impedance by cascading a transmission line junction to each port or simply reassigns the reference impedance to a specified complex value in Ohm.

Mixed-Mode S-Parameters converts single-ended S-parameters to mixed-mode S-parameters or vice versa.

Time Gating does a transformation from frequency domain to time domain, gates the data in time domain and transforms it back to frequency domain. See section 3.4.

Material Parameters provides the following tools:

- **Free-Space, Waveguide or Coaxial** computes material parameters from free-space, waveguide or coaxial S-parameter data, see section 3.5.1.
- **On-Wafer** computes material parameters from on-wafer S-parameter data, see section 3.5.2.

CMC Entry provides the following CMC tools:

- **Check CMC Uncertainties** verifies the uncertainties according to the selected CMC entry file.
- **Add CMC Uncertainties** adds additional CMC uncertainties to be in agreement with the selected CMC entry file.
- **Remove CMC Uncertainties** removes additional CMC uncertainties.

Database provides the following database tools:

- **Create Databased Standard** creates a databased standard[1], see section 4.6.3.
- **Fit Calibration Standard Model** computes the parameters of a calibration standard for an Agilent, Anritsu and Rohde Schwarz model[1], see appendix A.

Math provides the following math tools:

- **Add (1st + 2nd)** adds N-port 1 and N-port 2.
- **Subtract (1st - 2nd)** subtracts N-port 2 from N-port 1.
- **Subtract (2nd - 1st)** subtracts N-port 1 from N-port 2.
- **Multiply (1st x 2nd)** multiplies N-port 1 with N-port 2.
- **Divide (1st / 2nd)** divides N-port 1 by N-port 2.
- **Divide (2nd / 1st)** divides N-port 2 by N-port 1.

where 1st and 2nd are referring to the order of the two selected files.

Cascade provides the following cascade tools:

- **Cascade (1st and 2nd)** cascades $2N$-port 1 with N-port 2 or cascades 2-port 1 with 2-port 2.
- **Cascade (2nd and 1st)** cascades $2N$-port 2 with N-port 1 or cascades 2-port 2 with 2-port 1.
- **Cascade (inv(1st) and 2nd)** cascades inverted $2N$-port 1 with N-port 2 or cascades inverted 2-port 1 with 2-port 2.
- **Cascade (inv(2nd) and 1st)** cascades inverted $2N$-port 2 with N-port 1 or cascades inverted 2-port 2 with 2-port 1.
- **Cascade (1st and inv(2nd))** cascades N-port 1 with inverted $2N$-port 2 or cascades 2-port 1 with inverted 2-port 2.

Cascade (2nd and inv(1st)) cascades N-port 2 with inverted $2N$-port 1 or cascades 2-port 2 with inverted 2-port 1.

where 1st and 2nd are referring to the order of the two selected files.

Make Reciprocal makes an N-port reciprocal ($S_{jk} = S_{kj}$).

Merge (lower and upper) merges two data sets at a given frequency point.

Mean Data Set computes the mean of a data set.

Circle Fit Data Set computes the circle fit of a data set consisting of at least 3 measurements. The circle fit supports N-port data set where one port is terminated by a sliding load.

Properties shows the file or directory properties.

3.3 Visualization

The Data Explorer supports different view modes:

Graph shows a graphical visualization of multiple files, see section 3.3.1.

Table shows a tabular visualization of a single file, see section 3.3.2.

Point shows an uncertainty budget for one frequency point and one parameter of a single file, see section 3.3.3.

Covariance shows a covariance matrix for a single frequency point or a single parameter of a single file, see section 3.3.4.

Info shows file information including MD5 checksum of multiple files, see section 3.3.5.

3.3.1 Graph

The graph tab supports multiple selected files, see figure 4. The following user controls are available:

Setup sets up the plots (default: Sx,x Ports: 1, 2).

Conv sets the conversion to None, S/S', Passivity Check, Absorbed Power, Z-Parameter, Y-Parameter, Impedance, Admittance, Time Domain, Time Domain Impedance or Time Domain Admittance (default: None). See section 3.6 for more information.

MC sets the uncertainty propagation to Monte Carlo for formatting a complex quantity. Correlation between frequency points and different traces are ignored.

Format sets the data format to Real Imag, Mag Phase, ReIm MP (reflection real imag and transmission mag phase), Real, Imag, Mag, Phase or Cartesian (default: Mag Phase).

Freq log sets the frequency axis to linear or logarithmic (default: Freq lin).

[1] only single-ended S-parameter data

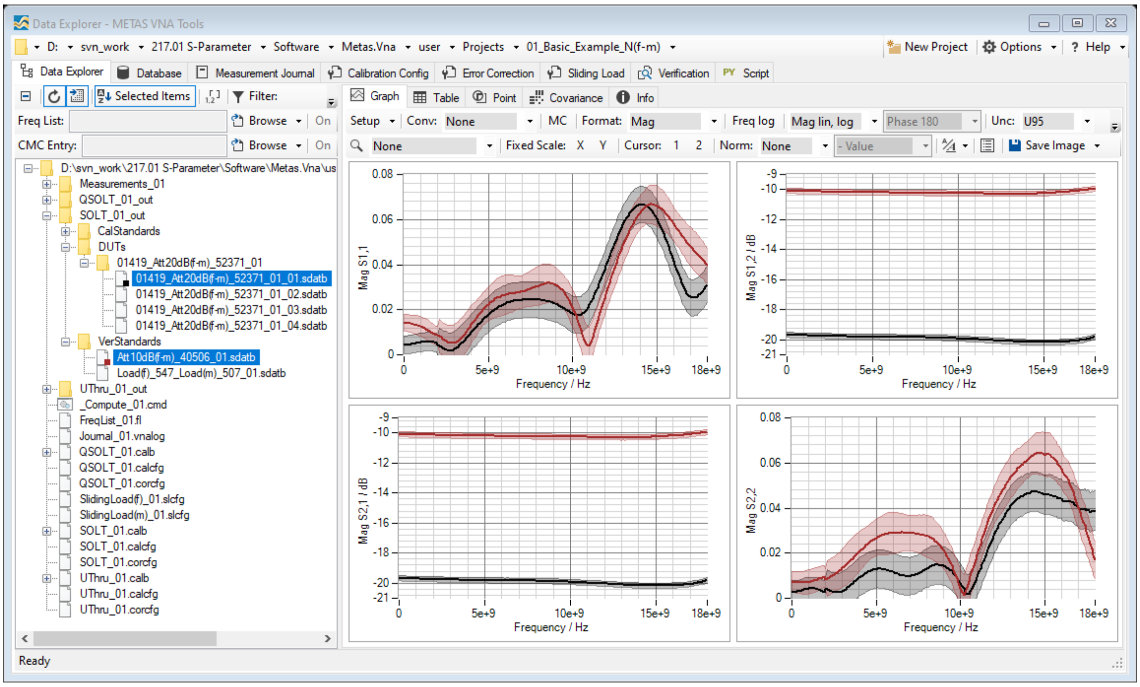

Figure 4: Data Explorer / Graph

Mag format sets the magnitude format to Mag lin (reflection and transmission linear), Mag log (reflection and transmission logarithmic), Mag lin log (reflection linear and transmission logarithmic), Mag^2 (reflection and transmission linear^2), VSWR lin (reflection VSWR and transmission linear) or VSWR log (reflection VSWR and transmission logarithmic) (default: Mag lin).

Phase format sets the phase format to Phase 180, Phase 360, Phase Unwrap, Phase Delay or Group Delay (default: Phase 180).

Time Domain Mode sets the time domain mode to Low Pass Step, Low Pass Impulse or Band Pass Impulse (default: Band Pass Impulse).

Window sets the window function used for transforming from frequency domain to time domain to Rectangular, Triangle, Hann, Hamming, Blackman, Blackman Harris, Blackman Nuttall, Exact Blackman, Flat Top, Minimum Kaiser ($\beta = 0$), Normal Kaiser ($\beta = 6$) or Maximum Kaiser ($\beta = 13$) (default: Normal Kaiser).

Unc sets the uncertainty mode to None, Standard or U95 (default: None).

Interaction Mode sets interaction mode to None, Zoom or Pan (default: None).

Fixed Scale activates or deactivates automatically scaling of the x- and y-axis.

Cursor shows or hides one or two cursors.

Norm normalizes all traces to one selected trace or to the mean value of all traces (default: None).

Norm Mode set the normalization mode to:

- **- Value** subtracts the value from the dataset.
- **- (Value + Unc)** subtracts the value and uncertainty from the dataset.
- / **Value** the dataset is divided by the value.
- / **(Value + Unc)** the dataset is divided by the value and uncertainty.

Font specifies the font for the current plots.

Legends shows or hides the legend.

Save Image saves the current plots to a bitmap file. Supported file formats are BMP, JPG and PNG.

Copy Image copies the current plots to the clipboard.

Table 2 shows the different colors for each trace and its associated uncertainty region.

Table 2: Trace Colors

Trace	Value	Unc	Color
1			black
2			brown
3			red
4			orange
5			yellow
6			green
7			blue
8			violet
9			gray
10			light gray

3.3.2 Table

The first of the selected files will be shown in the table view, see figure 5. The following user

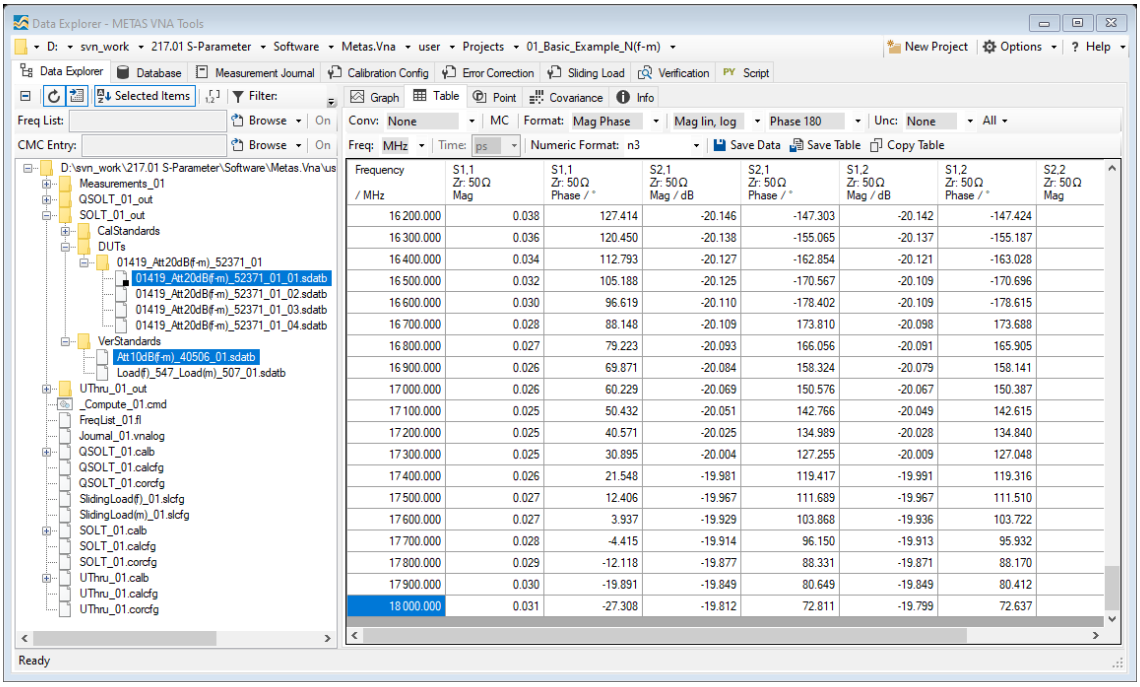

Figure 5: Data Explorer / Table

controls are available:

Conv sets the conversion to None, S/S', Passivity Check, Absorbed Power, Z-Parameter, Y-Parameter, Impedance, Admittance, Time Domain, Time Domain Impedance or Time Domain Admittance (default: None). See section 3.6 for more information.

MC sets the uncertainty propagation to Monte Carlo for formatting a complex quantity.

Format sets the data format to Real Imag, Mag Phase, ReIm MP (reflection real imag and transmission mag phase) or Mag (default: Mag Phase).

Mag format sets the magnitude format to Mag lin (reflection and transmission linear), Mag log (reflection and transmission logarithmic), Mag lin log (reflection linear and transmission logarithmic), Mag^2 (reflection and transmission linear^2), VSWR lin (reflection VSWR and transmission linear) or VSWR log (reflection VSWR and transmission logarithmic) (default: Mag lin).

Phase format sets the phase format to Phase 180, Phase 360, Phase Unwrap, Phase Delay or Group Delay (default: Phase 180).

Time Domain Mode sets the time domain mode to Low Pass Step, Low Pass Impulse or Band Pass Impulse (default: Band Pass Impulse).

Window sets the window function used for transforming from frequency domain to time domain to Rectangular, Triangle, Hann, Hamming, Blackman, Blackman Harris, Blackman Nuttall, Exact Blackman, Flat Top, Minimum Kaiser ($\beta = 0$), Normal Kaiser ($\beta = 6$) or Maximum Kaiser ($\beta = 13$) (default: Normal Kaiser).

Unc sets the uncertainty mode to None, Standard or U95 (default: None).

Freq sets the frequency format to Hz, kHz, MHz, GHz or THz (default: MHz).

Time sets the time format to s, ms, us, ns or ps (default: ps).

Numeric Format sets the numeric format (default: f3).

Save Data saves the current data in a file. Supported file formats are S-Parameter Data (*.sdatb or *.sdatx), S-Parameter Data Covariance Text (*.sdatcv), Touchstone (*.s1p, *.s2p, *.s*p), Touchstone V2.0 (*.ts), VNA Data (*.vdatb or *.vdatx), VNA Data Covariance Text (*.vdatcv) or CITI (*.cti or *.citi).

Save Table saves the current formatted data in a file. Supported file formats are Text (*.txt) or LaTeX(*.tex).

Copy Table copies the current formatted data to the clipboard.

One can select one or more rows of the table and copy the data to the clipboard with Ctrl-C or with the context menu of the table. Ctrl-A selects all data.

3.3.3 Point

The first of the selected files will be shown in the point view. One can select one frequency point and one parameter and obtains the uncertainty budget of the selected data point, see figure 6. The following user controls are available:

Freq selects a frequency point for the uncertainty budget (default: None).

Time selects a time point for the uncertainty budget (default: None). Only visible when conversation is set to Time Domain.

First selects the first frequency or time point.

Last selects the last frequency or time point.

Parameter selects a parameter for the uncertainty budget (default: None).

Conv sets the conversion to None, S/S', Passivity Check, Absorbed Power, Z-Parameter, Y-Parameter, Impedance, Admittance, Time Domain, Time Domain Impedance or Time Domain Admittance (default: None). See section 3.6 for more information.

MC sets the uncertainty propagation to Monte Carlo for formatting a complex quantity.

Format sets the format to Real, Imag, Mag, Mag log, Mag^2, VSWR, Phase, Phase 360, Phase Unwrap, Phase Delay or Group Delay (default: Mag).

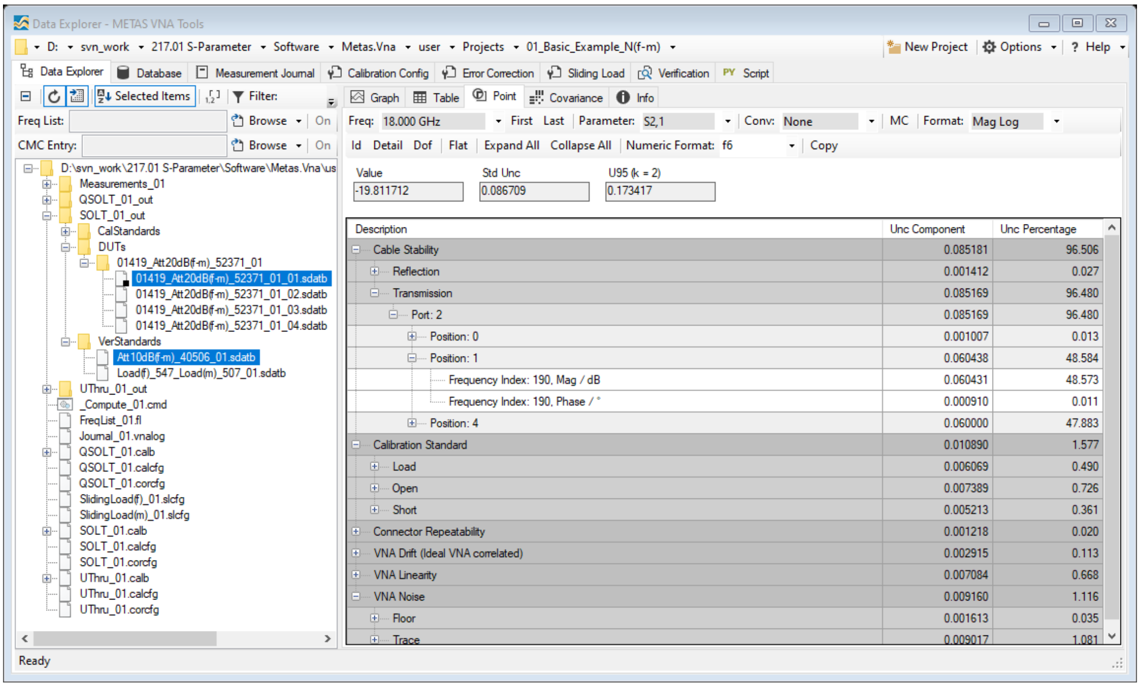

Figure 6: Data Explorer / Point

Time Domain Mode sets the time domain mode to Low Pass Step, Low Pass Impulse or Band Pass Impulse (default: Band Pass Impulse).

Window sets the window function used for transforming from frequency domain to time domain to Rectangular, Triangle, Hann, Hamming, Blackman, Blackman Harris, Blackman Nuttall, Exact Blackman, Flat Top, Minimum Kaiser ($\beta = 0$), Normal Kaiser ($\beta = 6$) or Maximum Kaiser ($\beta = 13$) (default: Normal Kaiser).

Id shows or hides the uncertainty input ids (default: Hide).

Detail shows or hides the distribution, value, standard uncertainty and sensitivity columns (default: Hide).

Dof shows or hides the degrees of freedom (default: Hide).

Flat shows a flat or tree uncertainty budget (default: Tree).

Expand All expands all tree nodes.

Collapse All collapses all tree nodes.

Numeric Format sets the numeric format (default: f6).

Copy copies the uncertainty budget to the clipboard.

The following items will be shown for the selected data point:

Value indicates the value.

Std Unc shows the standard uncertainty (68% coverage factor, $k = 1$).

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

Unc Budget shows a tabular visualization of the uncertainty budget.

3.3.4 Covariance

The first of the selected files will be shown in the covariance view. There are two modes in the covariance view. Either one can select a single frequency point and obtains the covariance matrix of multiple parameters at the selected frequency point. Or one can select all frequency points and a single parameter in the desired format and obtains the covariance matrix for the selected parameter and format over the hole frequency range, see figure 7. The following user

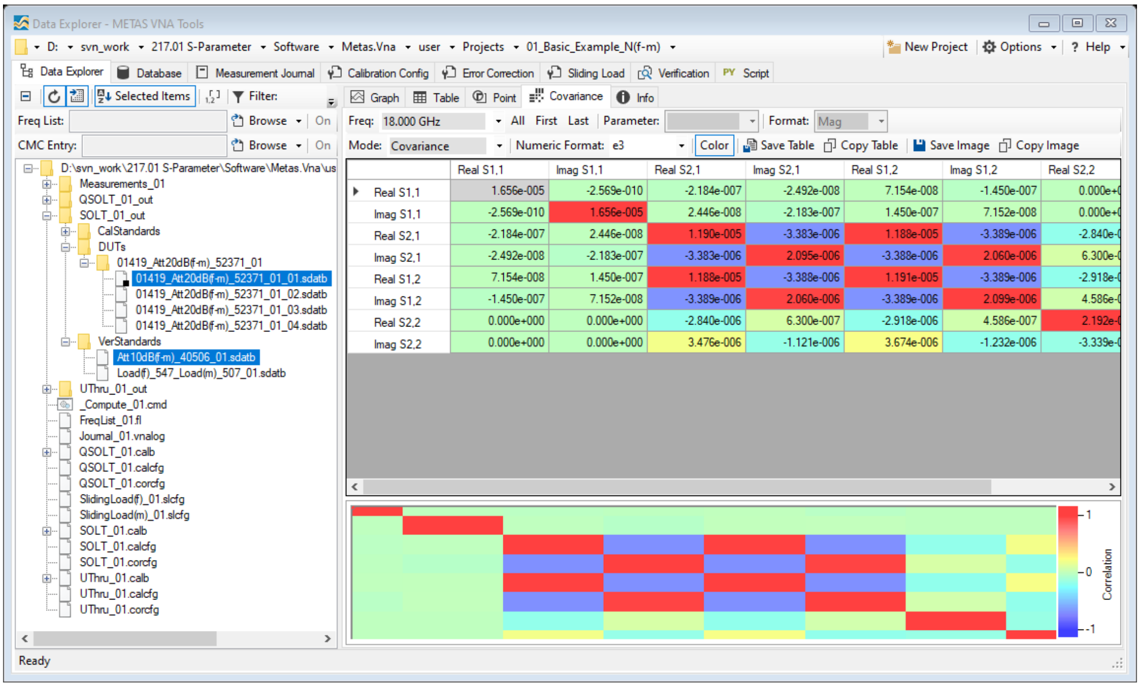

Figure 7: Data Explorer / Covariance

controls are available:

Freq selects a frequency point or all frequency points for the covariance view (default: None).

All selects all frequency points.

First selects the first frequency point.

Last selects the last frequency point.

Parameter selects a parameter for the covariance view (default: None).

Format sets the format to Real, Imag, Mag or Phase (default: Mag).

Mode sets the mode to covariance or correlation (default: Covariance).

Numeric Format sets the numeric format (default: e3).

Color shows or hides the graphical representation of the correlation matrix (default: show).

Save Table saves the current formatted covariance in a file. Supported file formats are Text (*.txt) or LaTeX(*.tex).

Copy Table copies the current formatted covariance to the clipboard as text.

Save Image saves the current covariance to a bitmap file. Supported file formats are BMP, JPG and PNG.

Copy Image copies the current covariance to the clipboard as bitmap.

3.3.5 Info

The info tab supports multiple selected files. One can obtain information about multiple files by holding the Ctrl or Shift key and selecting the files. The info tab shows the file name, size, modification date and computes the checksum for each selected file. See Figure 8. The

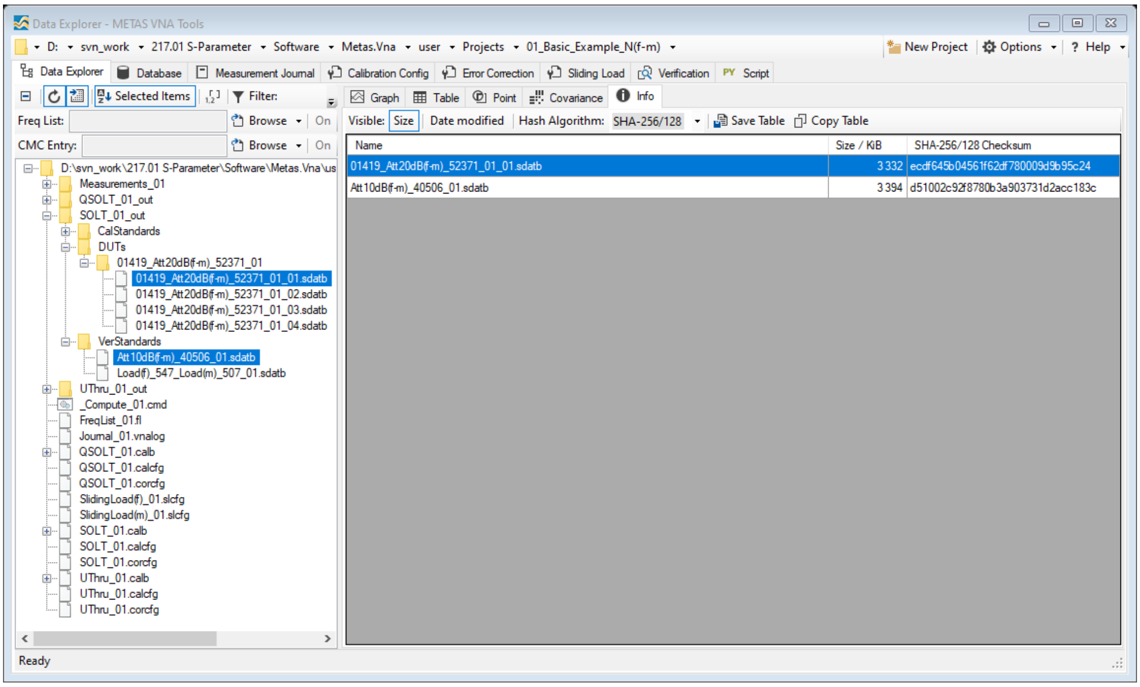

Figure 8: Data Explorer / Info

following user controls are available:

Size shows or hides the file sizes (default: Show).

Data modified shows or hides the file dates (default: Hide).

Hash Algorithm specifies the used hash algorithm to compute the checksum (default: SHA-256/128).

Save Table saves the current information in a file. Supported file formats are Text (*.txt) or LaTeX(*.tex).

Copy Table copies the current information to the clipboard.

3.4 Time Gating

The dialog called Time Gating, see figure 9, is designed to gate S-parameter data in time domain and transform it back to frequency domain. The following user controls are available:

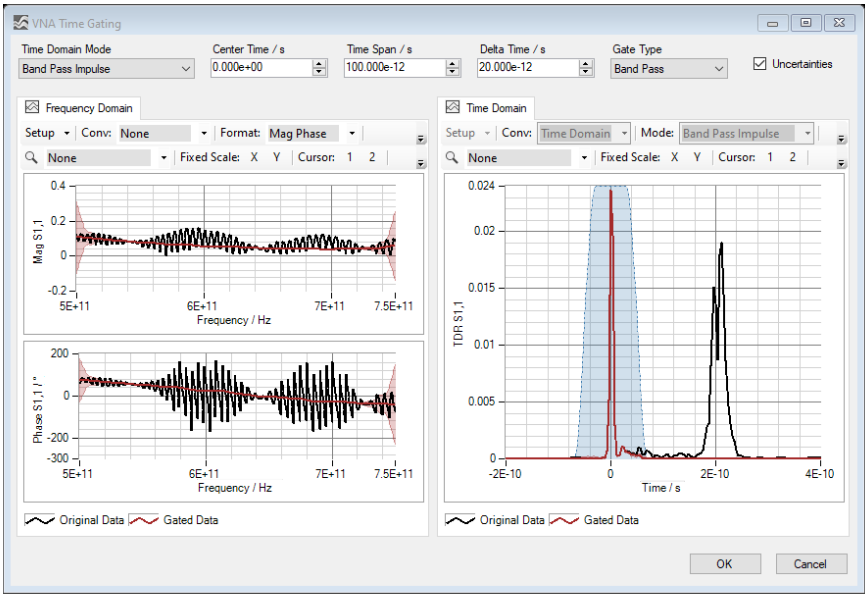

Figure 9: Data Explorer / Time Gating

Time Domain Mode sets the time domain mode to Low Pass Step, Low Pass Impulse or Band Pass Impulse (default: Band Pass Impulse).

Center Time / s specifies the time of the center of the gate shape (default: 0 ps).

Time Span / s specifies the time span from 50 % to 50 % of the gate shape (default: 100 ps).

Delta Time / s specifies the delta time from 0 % to 50 % or from 50 % to 100 % of the gate shape (default: 20 ps). The Time Span must be at least two times the Delta Time.

Gate Type sets the gate type to Band Pass or Notch (default: Band Pass).

Uncertainties enables uncertainty propagation. Note that time gating with more than 1000 frequency points and uncertainty propagation is very memory and time consuming.

Frequency Domain shows a graphical visualization of the original data and the gated data in frequency domain.

Time Domain shows a graphical visualization of the original data, the gated data and the gate shape in time domain.

3.5 Material Parameters

3.5.1 Free-Space, Waveguide or Coaxial

The dialog called Material Parameters, see figures 10 and 11, is designed to compute material parameters from free-space, waveguide or coaxial S-parameter data. The reference impedance Z_r of the S-parameter data must be equal to the characteristic impedance of the embedding transmission line. In VNA Tools $Z_r = 1\,\Omega$ means that the reference impedance equals the characteristic impedance. Thus it is checked if $Z_r = 1\,\Omega$ is set. Usually S-parameters in free-space and waveguide are referenced to their characteristic impedance and no further action has to be taken. Note that coaxial measurements have to be re-normalized to the characteristic impedance of the embedding line. This can be done in the dialog called change reference impedance, see section 3.2.1. The following user controls are available:

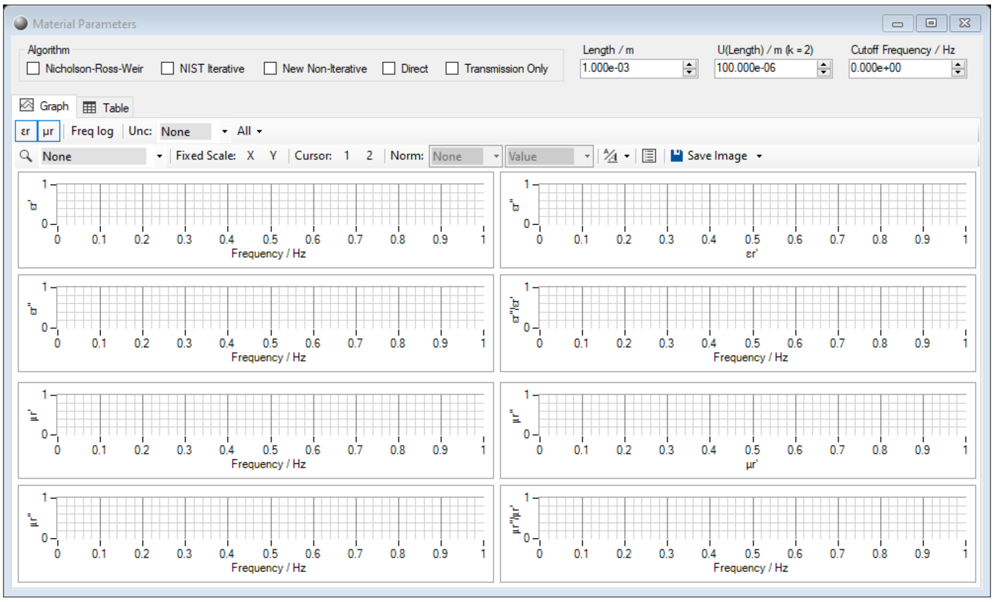

Figure 10: Data Explorer / Material Parameters / Free-Space, Waveguide or Coaxial / Graph

Algorithm specifies one or multiple algorithms. The following algorithms are available:

> **Nicholson-Ross-Weir** (relative permittivity ε_r and relative permeability μ_r)
>
> **NIST Iterative** (relative permittivity ε_r)
>
> **New Non-Iterative** (relative permittivity ε_r)
>
> **Direct** (relative permittivity ε_r)
>
> **Transmission Only** (relative permittivity ε_r)

Length / m specifies the value and the uncertainty ($k = 2$) of the length / thickness of the sample in m.

Cutoff Frequency / Hz specifies the waveguide cutoff frequency in Hz.

The previously selected files from the Data Explorer using the selected algorithm choices will be shown in the graph, see figure 10. The following tools are available:

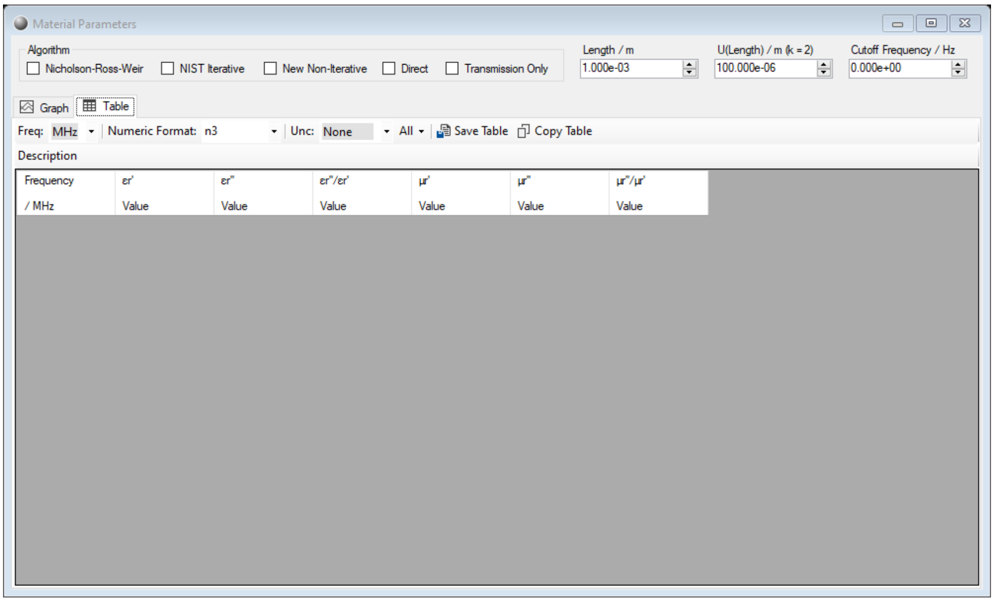

Figure 11: Data Explorer / Material Parameters / Free-Space, Waveguide or Coaxial / Table

Relative Permittivity ε_r shows or hides the relative permittivity plots.

Relative Permeability μ_r shows or hides the relative permeability plots.

Freq log sets the frequency axis to linear or logarithmic (default: Freq lin).

Unc sets the uncertainty mode to None, Standard or U95 (default: None).

Interaction Mode sets interaction mode to None, Zoom or Pan (default: None).

Fixed Scale activates or deactivates automatically scaling of the x- and y-axis.

Cursor shows or hides one or two cursors.

Norm normalizes all traces to one selected trace or to the mean value of all traces (default: None).

Norm Mode set the normalization mode to:

- Value subtracts the value from the dataset.

- (Value + Unc) subtracts the value and uncertainty from the dataset.

/ **Value** the dataset is divided by the value.

/ **(Value + Unc)** the dataset is divided by the value and uncertainty.

Font specifies the font for the current plots.

Legends shows or hides the legend.

Save Image saves the current plots to a bitmap file. Supported file formats are BMP, JPG and PNG.

Copy Image copies the current plots to the clipboard.

The first of the previously selected files from the Data Explorer using the first selected algorithm choice will be shown in the table view, see figure 11. The following tools are available:

Freq sets the frequency format to Hz, kHz, MHz, GHz or THz (default: MHz).

Numeric Format sets the numeric format (default: f3).

Unc sets the uncertainty mode to None, Standard or U95 (default: None).

Save Table saves the current formatted data in a file. Supported file formats are Text (*.txt) or LaTeX(*.tex).

Copy Table copies the current formatted data to the clipboard.

One can select one or more rows of the table and copy the data to the clipboard with Ctrl-C or with the context menu of the table. Ctrl-A selects all data.

3.5.2 On-Wafer

The dialog called On-Wafer Material Parameters, see figures 12, 13 and 14, is designed to compute material parameters from on-wafer S-parameter data. The following user controls

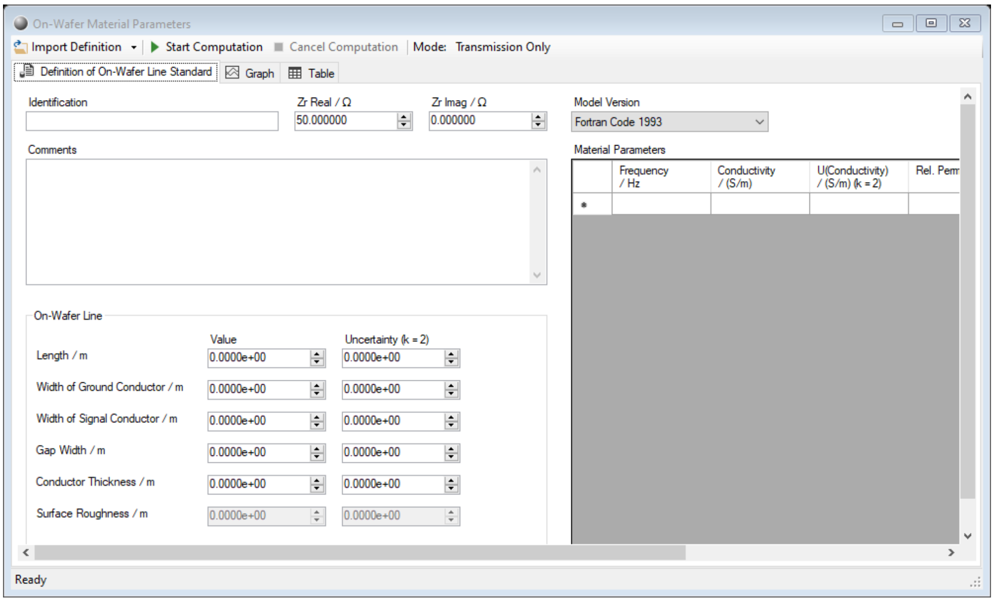

Figure 12: Data Explorer / Material Parameters / On-Wafer / Definition

are available:

Import Definition imports an on-wafer line standard from the database.

Start Computation starts optimization of the relative permittivity and tan delta.

Cancel Computation aborts optimization.

Transmission Only sets the mode to transmission only.

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Length / **m** sets the value and the uncertainty ($k = 2$) of the length of the line in m.

Width of Ground Conductor / **m** sets the value and the uncertainty ($k = 2$) of the width of the ground conductor in m.

Width of Signal Conductor / **m** sets the value and the uncertainty ($k = 2$) of the width of the signal conductor in m.

Gap Width / **m** sets the value and the uncertainty ($k = 2$) of the gap width in m.

Conductor Thickness / **m** sets the value and the uncertainty ($k = 2$) of the conductor thickness in m.

Surface Roughness / **m** sets the value and the uncertainty ($k = 2$) of the surface roughness in m.

Variable Gamma specifies if γ is variable.

Model Version specifies the version of the used model. The following versions are available:

- Heinrich Paper 1993
- Fortran Code 1993 (default)
- Schnieder Paper 2003
- Gold Paper 2019
- Phung Paper 2021

Material Parameters is a table with the following columns:

- Frequency in Hz
- Conductivity in S/m
- U(Conductivity) in S/m with $k = 2$
- Relative Permittivity
- U(Relative Permittivity) with $k = 2$
- Tan delta
- U(Tan delta) with $k = 2$

The relative permittivity and tan delta columns are used as start values for the optimization.

The material parameters of the previously selected files from the Data Explorer will be shown in the graph, see figure 13. The following tools are available:

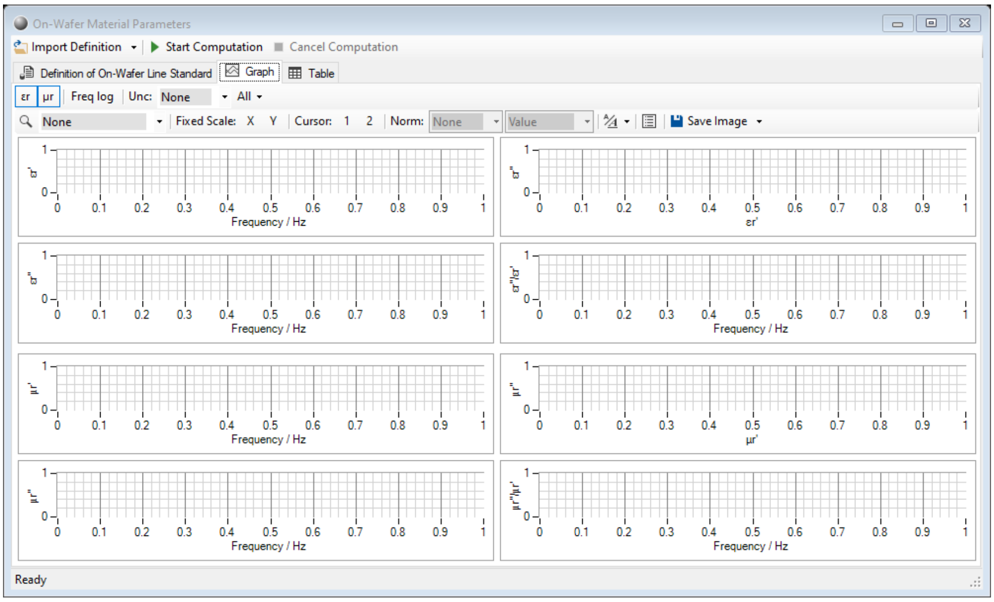

Figure 13: Data Explorer / Material Parameters / On-Wafer / Graph

Relative Permittivity ε_r shows or hides the relative permittivity plots.

Relative Permeability μ_r shows or hides the relative permeability plots.

Freq log sets the frequency axis to linear or logarithmic (default: Freq lin).

Unc sets the uncertainty mode to None, Standard or U95 (default: None).

Interaction Mode sets interaction mode to None, Zoom or Pan (default: None).

Fixed Scale activates or deactivates automatically scaling of the x- and y-axis.

Cursor shows or hides one or two cursors.

Norm normalizes all traces to one selected trace or to the mean value of all traces (default: None). In the neighboring control one can select if normalization is with respect to value or value and uncertainty. Normalizing to a value means subtracting certain values from the dataset. The resulting uncertainties are the same as from the input data. Normalizing to value and uncertainty means subtracting uncertain numbers from the dataset. The resulting uncertainties are different from the previous case because the uncertainties are as well subtracted.

Font specifies the font for the current plots.

Legends shows or hides the legend.

Save Image saves the current plots to a bitmap file. Supported file formats are BMP, JPG and PNG.

Copy Image copies the current plots to the clipboard.

The material parameters of the first of the previously selected files from the Data Explorer will be shown in the table view, see figure 14. The following tools are available:

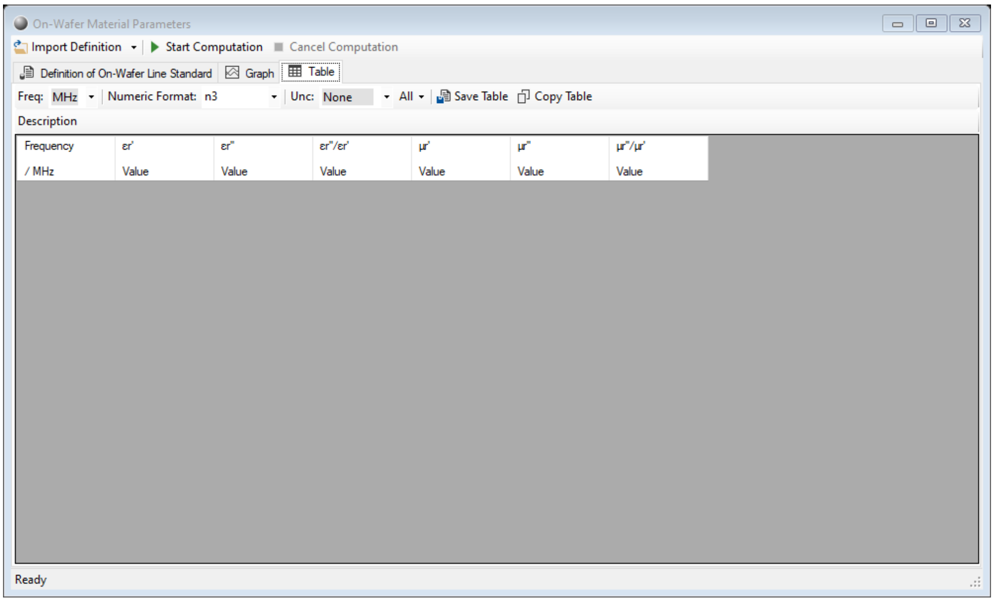

Figure 14: Data Explorer / Material Parameters / On-Wafer / Table

Freq sets the frequency format to Hz, kHz, MHz, GHz or THz (default: MHz).

Numeric Format sets the numeric format (default: f3).

Unc sets the uncertainty mode to None, Standard or U95 (default: None).

Save Table saves the current formatted data in a file. Supported file formats are Text (*.txt) or LaTeX(*.tex).

Copy Table copies the current formatted data to the clipboard.

One can select one or more rows of the table and copy the data to the clipboard with Ctrl-C or with the context menu of the table. Ctrl-A selects all data.

3.6 Math

The same equations are used in Graph, Table and Point tab for data conversion and formatting. Table 3 shows the equations for data conversions in METAS VNA Data Explorer. Variable x is the input quantity, y is the converted output, Z_r is the reference impedance and Y_r is the reference admittance. Index i is the frequency point, j is the receiver port and k is the source port. Table 4 shows the equations used for data formatting. Variable y is the converted input

Table 3: Conversions

Conversion	Equation
None	$y = x$
S/S'	$y_{jk} = x_{jk}/x_{kj}$
Passivity Check	$y_{jk} = (\mathrm{eig}\left(\mathbf{I} - \mathbf{X}^{*}\mathbf{X}\right))_{jk}$
Absorbed Power	$y_{jk} = (\mathrm{AbsorbedPower}\left(\mathbf{X}\right))_{jk}$
Z-Parameter	$y_{jk} = \left(\left(\mathbf{I} + \mathbf{X}\right)\left(\mathbf{I} - \mathbf{X}\right)^{-1}\right)_{jk} Z_r$
Y-Parameter	$y_{jk} = \left(\left(\mathbf{I} - \mathbf{X}\right)\left(\mathbf{I} + \mathbf{X}\right)^{-1}\right)_{jk} Y_r$
Impedance	$y = \frac{1+x}{1-x} Z_r$
Admittance	$y = \frac{1-x}{1+x} Y_r$
Time Domain	$y = \mathrm{FDtoTD}\left(x, mode, window\right)$
TD Impedance	$y = \frac{1+t}{1-t} Z_r$ with $t = \mathrm{FDtoTD}\left(x, mode, window\right)$
TD Admittance	$y = \frac{1-t}{1+t} Y_r$ with $t = \mathrm{FDtoTD}\left(x, mode, window\right)$

from Table 3 and z is the formatted output.

Table 4: Formats

Format	Equation
Real	$z = \Re(y)$
Imag	$z = \Im(y)$
Mag	$z = \lvert y\rvert$
Mag log	$z = 20\log_{10}(\lvert y\rvert)$
Mag^2	$z = \lvert y\rvert^2$
VSWR	$z = \frac{1+\lvert y\rvert}{1-\lvert y\rvert}$
Phase	$z = \frac{180°}{\pi}\arg(y)$
Phase 360	$z = \begin{cases} \frac{180°}{\pi}\arg(y) & ,\arg(y) \le 0 \\ \frac{180°}{\pi}\arg(y) - 360° & ,\arg(y) > 0 \end{cases}$
Phase Unwrap	$z = \frac{180°}{\pi}\operatorname{unwrap}(\arg(y))$
Phase Delay	$z_i = -\frac{\varphi_i}{2\pi f_i}$ with $\varphi = \operatorname{unwrap}(\arg(y))$
Group Delay	$z_i = \begin{cases} -\frac{\varphi_2-\varphi_1}{2\pi(f_2-f_1)} & ,i=1 \\ -\frac{\varphi_{i+1}-\varphi_{i-1}}{2\pi(f_{i+1}-f_{i-1})} & ,1<i \wedge i<n \\ -\frac{\varphi_n-\varphi_{n-1}}{2\pi(f_n-f_{n-1})} & ,i=n \end{cases}$ with $\varphi = \operatorname{unwrap}(\arg(y))$

3.7 Uncertainty

There are three different uncertainty modes:

None hides the uncertainty.

Standard shows the standard uncertainty. In a scalar case this means 68% coverage and $k = 1$. In a two dimensional case this means 39% coverage and $k = 1$.

U95 shows the expanded uncertainty. In a scalar case this means 95% coverage and $k = 2$. In a two dimensional case this means 95% coverage and $k = 2.45$.

Here a scalar quantity consist of only one component, e.g. magnitude of S-parameter, whereas a two dimensional quantity consists of two components, e.g. complex S-parameter. In graphical representations the dimension is determined by the number of components shown in one subplot.

The uncertainties are computed with linear uncertainty propagation. This leads to well known problems when computing the absolute value and phase of small quantities.

4 Database

The Databased is designed to specify values and uncertainties of VNA devices, cables, connectors, DUT uncertainties, calibration standards, CMC entries and logger devices.

4.1 VNA Device

The VNA Device tabular page is designed to specify VNA devices in the database, see figure 15. The following user controls are available:

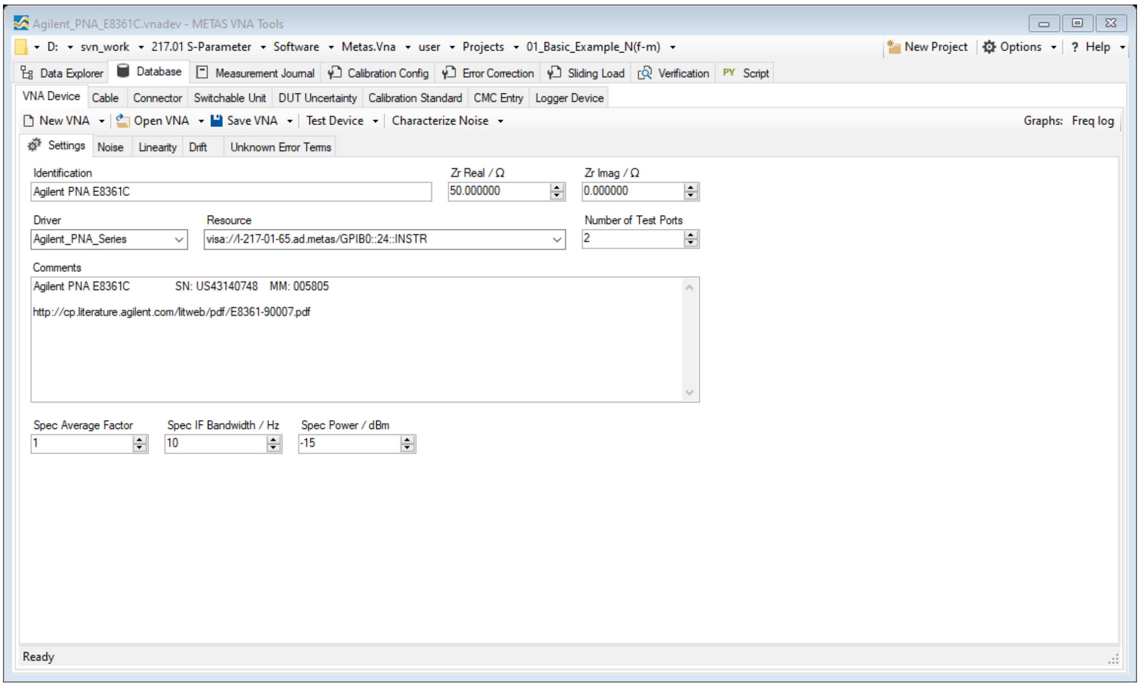

Figure 15: Database / VNA Device / Settings

New VNA creates a new database item of the type VNA device (shortcut: Ctrl + N).

Open VNA loads a VNA item from a file (*.vnadev), (shortcut: Ctrl + O).

Save VNA saves the VNA item to a file (*.vnadev), (shortcut: Ctrl + S).

Test Device tests VNA device if VISA connection is possible.

VNA Test Panel opens a VNA test panel.

NI-VISA Test Panel opens a VISA test panel.

Characterize Noise characterizes and analyzes the noise of the VNA at the specified frequency points, average factor, IF bandwidth, power level, settling points and moving mean points, see section 4.1.3.

Analyze Noise analyzes the noise of the VNA using the last noise characterization at the specified settling points and moving mean points.

Freq log sets the frequency axis to linear or logarithmic (default: Freq lin).

4.1.1 Settings

The following user controls are available on the sub tabular page called Settings:

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Driver sets the driver for the communication with the VNA device.

Resource sets the VISA resource name of the VNA device. VISA resources are the addresses of devices connected to the computer. VISA is a standard which is accepted by nearly all manufactures of VNAs.

Number of Test Ports specifies the number of test ports.

Comments field can contain user comments.

Spec Average Factor specifies the average factor used for the noise specification.

Spec IF Bandwidth / **Hz** specifies the IF bandwidth used for the noise specification.

Spec Power / **dBm** specifies the power level used for the noise floor and linearity specification.

4.1.2 Noise

The next sub tabular page is called Noise, see figure 16. It contains a table with the following columns:

- Frequency in Hz
- Noise Floor of the S-parameters for each receiving port in dB with $k = 1$
- Trace Noise Mag of the S-parameters for each receiving port in dB with $k = 1$
- Trace Noise Phase of the S-parameters for each receiving port in deg with $k = 1$
- Noise Floor for each test receiver in dBm with $k = 1$
- Trace Noise Mag for each test receiver in dB with $k = 1$
- Trace Noise Phase for each test receiver in deg with $k = 1$
- Noise Floor for each reference receiver in dBm with $k = 1$
- Trace Noise Mag for each reference receiver in dB with $k = 1$
- Trace Noise Phase for each reference receiver in deg with $k = 1$

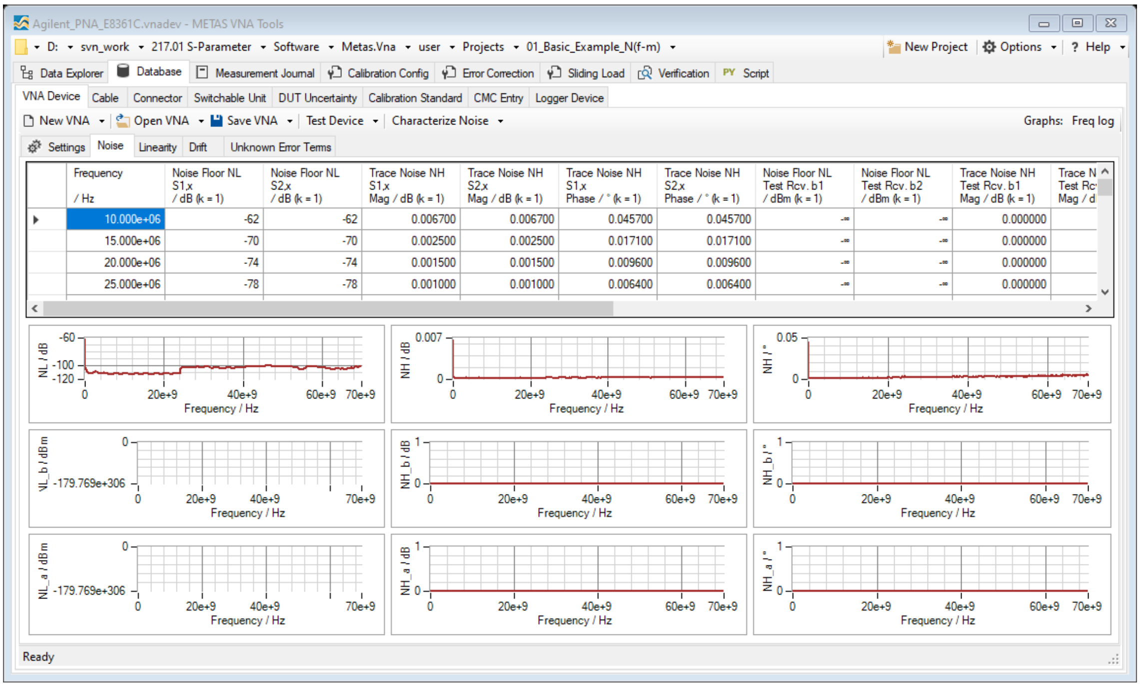

Figure 16: Database / VNA Device / Noise

and the following graphs:

NL / dB shows the noise floor of the S-parameters for each receiving test port in dB.

NH / dB shows the magnitude of the trace noise of the S-parameters for each receiving test port in dB.

NH / ° shows the phase of the trace noise of the S-parameters for each receiving test port in degree.

NL_b / dBm shows the noise floor of each test receiver in dBm.

NH_b / dB shows the magnitude of the trace noise of each test receiver in dB.

NH_b / ° shows the phase of the trace noise of each test receiver in degree.

NL_a / dBm shows the noise floor of each reference receiver in dBm.

NH_a / dB shows the magnitude of the trace noise of each reference receiver in dB.

NH_a / ° shows the phase of the trace noise of each reference receiver in degree.

The different traces represent the different test ports where black is port 1, brown is port 2, red is port 3, orange port 4 and so on. The trace colors are according to the resistor code, see table 2.

4.1.3 Characterize Noise

The dialog called Characterize Noise, see figure 17, is designed to characterize and analyze the noise floor and trace noise of a VNA. This is done by connecting a high reflect to each test port and measuring the S-parameters or optional the test and reference receivers. For the noise characterization each frequency is measured in continuous wave (CW) mode to minimize drift effects. The following user controls are available:

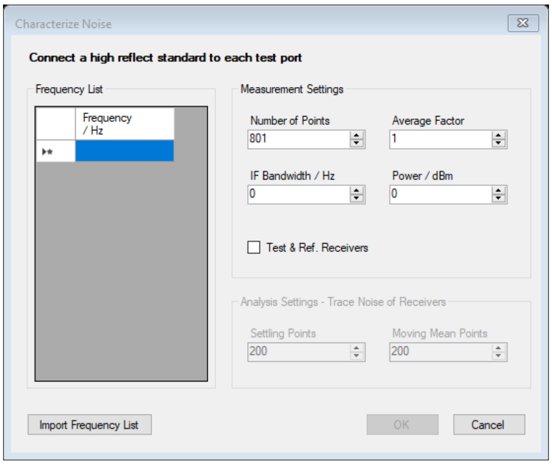

Figure 17: Database / VNA Device / Characterize Noise

Frequency List specifies the frequency list in Hz used for the noise characterization.

Import Frequency List imports an existing frequency list.

The following measurement settings are available:

Number of Points sets the number of points per frequency point used for the noise characterization.

Average Factor sets the average factor used for the noise characterization.

IF Bandwidth / Hz sets the IF bandwidth in Hz used for the noise characterization.

Power / dBm sets the power level in dBm used for the noise characterization.

Test & Ref. Receivers performs noise characterization for wave parameters and not only for S-parameters.

The following analysis settings for the trace noise of the receivers are available:

Settling Points specifies the number of settling points which are removed at the beginning of the collected data. This is to mask settling issues which typically happen after switch the source to another port.

Moving Mean Points specifies the number of moving mean points. The moving mean is subtracted from the truncated collected data to separate noise and drift.

4.1.4 Linearity

The next sub tabular page contains two tables and is called Linearity, see figure 18. The first specifies the different power levels in dB. The second table contains the following columns:

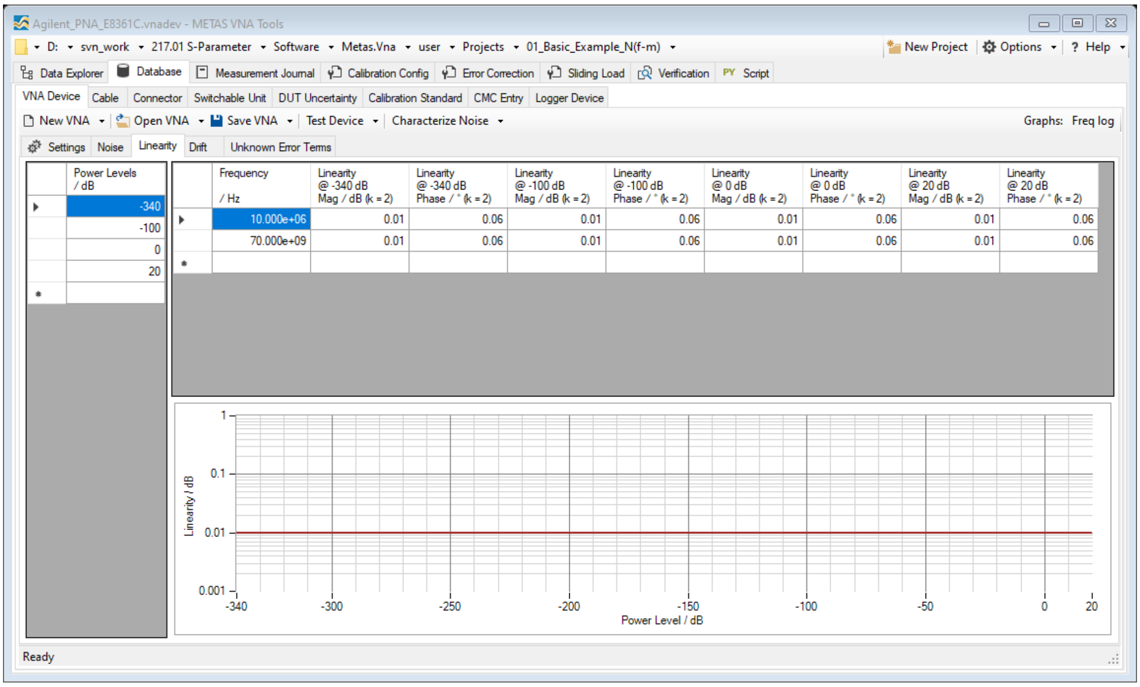

Figure 18: Database / VNA Device / Linearity

- Frequency in Hz
- Linearity Mag in dB with $k = 2$, one column for each power level
- Linearity Phase in deg with $k = 2$, one column for each power level

4.1.5 Drift

The next sub tabular page is called Drift, see figure 19. It contains a table with the following columns:

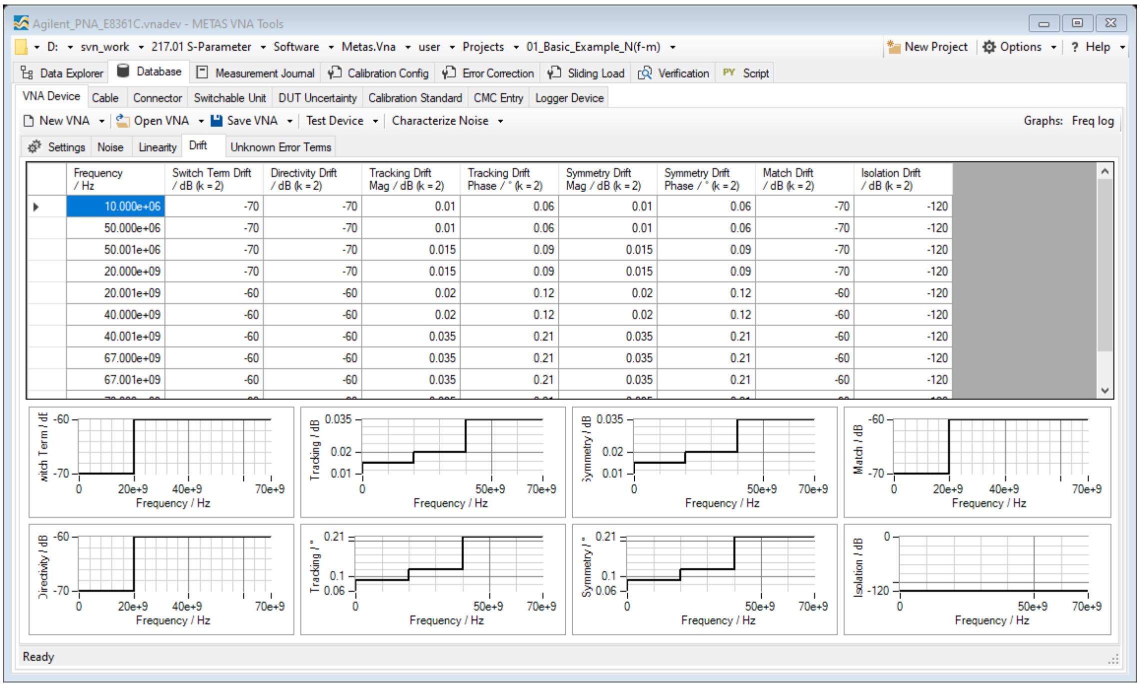

Figure 19: Database / VNA Device / Drift

- Frequency in Hz
- Switch Term Drift in dB with $k = 2$
- Directivity Drift in dB with $k = 2$
- Tracking Drift Mag in dB with $k = 2$
- Tracking Drift Phase in deg with $k = 2$
- Symmetry Drift Mag in dB with $k = 2$
- Symmetry Drift Phase in deg with $k = 2$
- Match Drift in dB with $k = 2$
- Isolation Drift in dB with $k = 2$

4.1.6 Unknown Error Terms

The next sub tabular page is called Unknown Error Terms, see figure 20. It contains a table with the following columns:

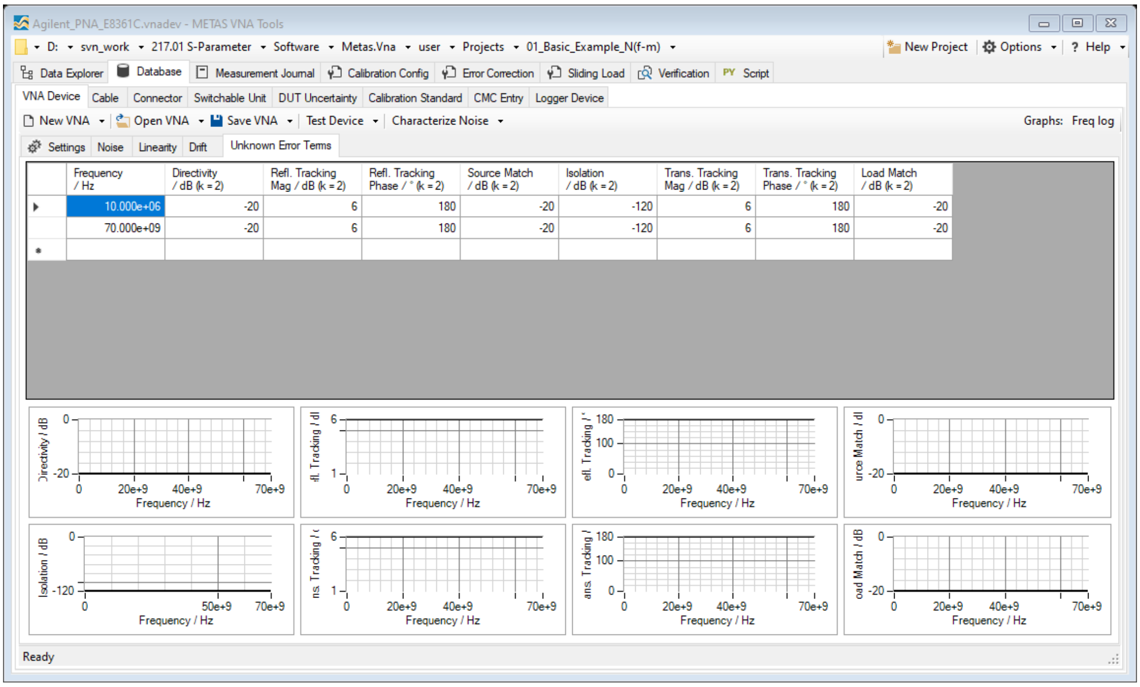

Figure 20: Database / VNA Device / Unknown Error Terms

- Frequency in Hz
- Directivity in dB with $k = 2$
- Reflection Tracking Mag in dB with $k = 2$
- Reflection Tracking Phase in deg with $k = 2$
- Source Match in dB with $k = 2$
- Isolation in dB with $k = 2$
- Transmission Tracking Mag in dB with $k = 2$
- Transmission Tracking Phase in deg with $k = 2$
- Load Match in dB with $k = 2$

4.2 Cable

The tabular page, called Cable, is designed to specify cables in the database, see figure 21. The following user controls are available:

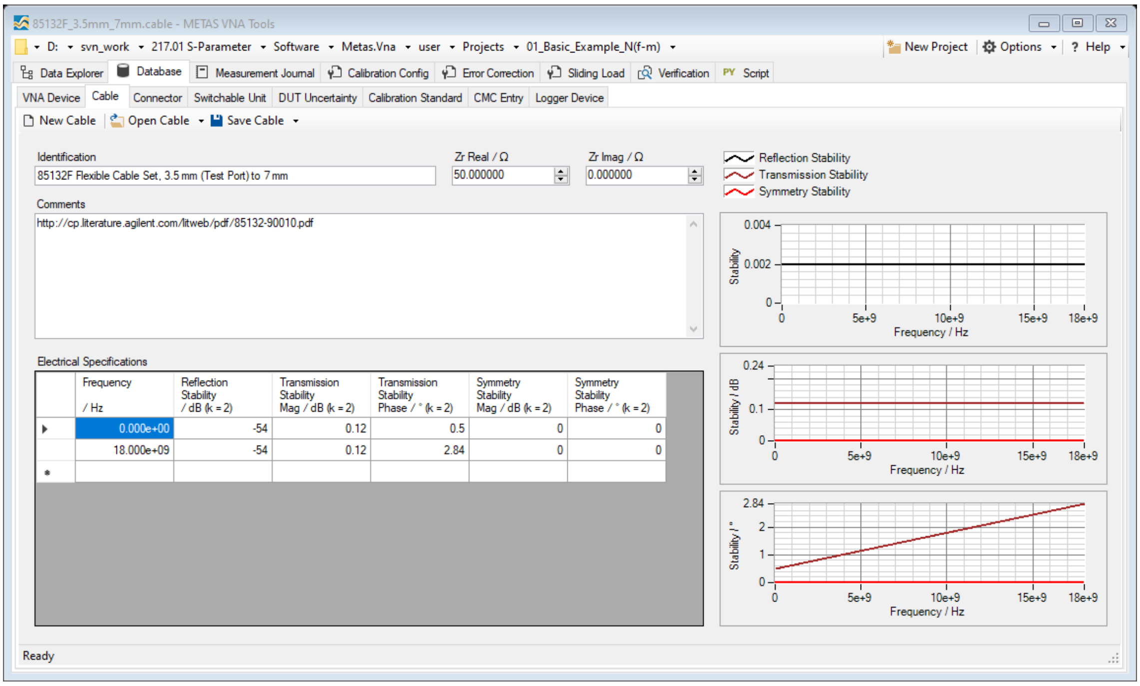

Figure 21: Database / Cable

New Cable creates a new database item of the type cable (shortcut: Ctrl + N).

Open Cable loads a cable from a file (*.cable), (shortcut: Ctrl + O).

Save Cable saves the cable to a file (*.cable), (shortcut: Ctrl + S).

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz
- Reflection Stability in dB with $k = 2$
- Transmission Stability Mag in dB with $k = 2$
- Transmission Stability Phase in deg with $k = 2$
- Symmetry Stability Mag in dB with $k = 2$
- Symmetry Stability Phase in deg with $k = 2$

4.3 Connector

The Connector tabular page is designed to specify connectors in the database, see figure 22. The following user controls are available:

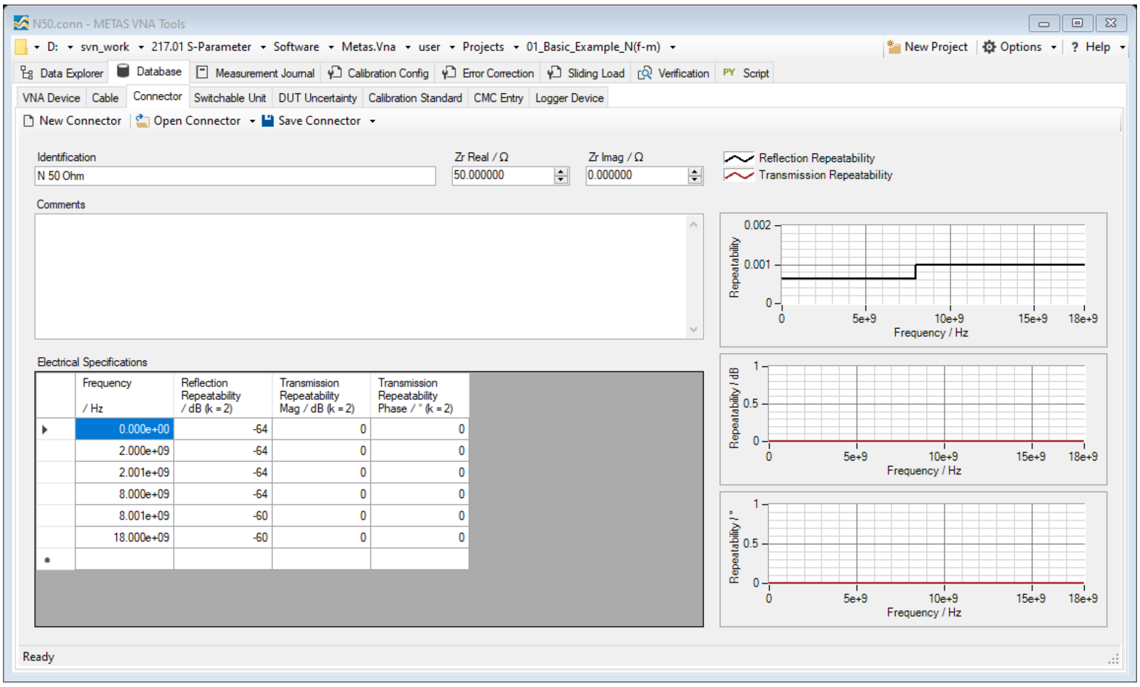

Figure 22: Database / Connector

New Connector creates a new database item of the type connector (shortcut: Ctrl + N).

Open Connector loads a connector from a file (*.conn), (shortcut: Ctrl + O).

Save Connector saves the connector to a file (*.conn), (shortcut: Ctrl + S).

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz
- Reflection Repeatability in dB with $k = 2$
- Transmission Repeatability Mag in dB with $k = 2$
- Transmission Repeatability Phase in deg with $k = 2$

4.4 Switchable Unit

The Switchable Unit tabular page is designed to specify switchable units in the database, see figure 23. The following user controls are available:

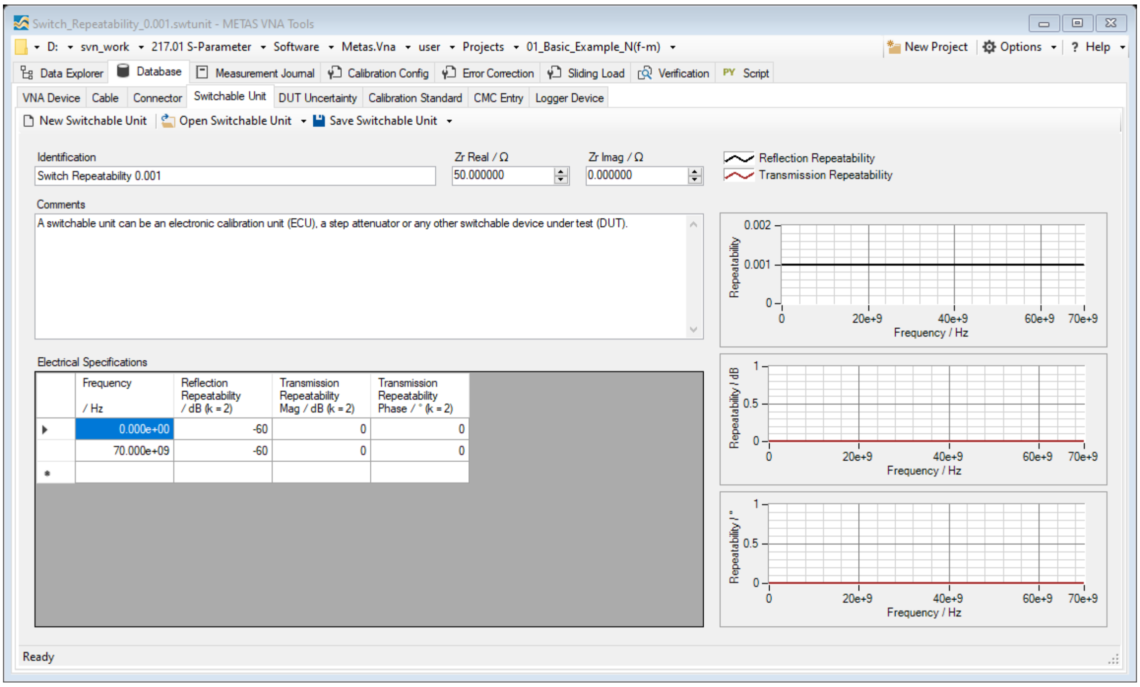

Figure 23: Database / Switchable Unit

New Switchable Unit creates a new database item of the type switchable unit (shortcut: Ctrl + N).

Open Switchable Unit loads a switchable unit from a file (*.swtunit), (shortcut: Ctrl + O).

Save Switchable Unit saves the switchable unit to a file (*.swtunit), (shortcut: Ctrl + S).

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz
- Reflection Repeatability in dB with $k = 2$
- Transmission Repeatability Mag in dB with $k = 2$
- Transmission Repeatability Phase in deg with $k = 2$

A switchable unit can be an electronic calibration unit (ECU), a step attenuator or any other switchable device under test (DUT).

4.5 DUT Uncertainty

The DUT Uncertainty tabular page is designed to specify additional DUT uncertainties in the database, see figure 24. The following user controls are available:

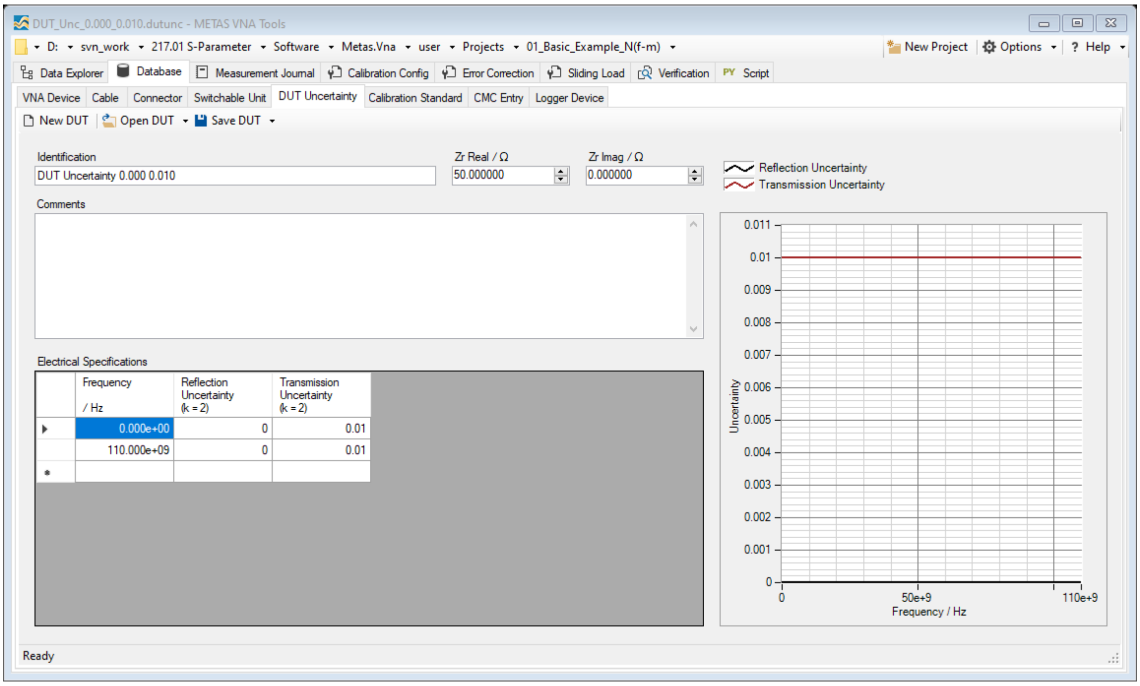

Figure 24: Database / DUT Uncertainty

New DUT creates a new database item of the type DUT uncertainty (shortcut: Ctrl + N).

Open DUT loads a DUT uncertainty from a file (*.dutunc), (shortcut: Ctrl + O).

Save DUT saves the DUT Uncertainty to a file (*.dutunc), (shortcut: Ctrl + S).

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz
- Reflection Uncertainty with $k = 2$
- Transmission Uncertainty with $k = 2$

The DUT uncertainty can be used to represent the crosstalk in on-wafer measurements. In this case the DUT uncertainty is uncorrelated for every standard on the wafer and it's correlated for multiple measurements of the same standard.

4.6 Calibration Standard

The tabular page, called Calibration Standard, is designed to specify calibration standards in the database, see figure 25. The following user controls are available:

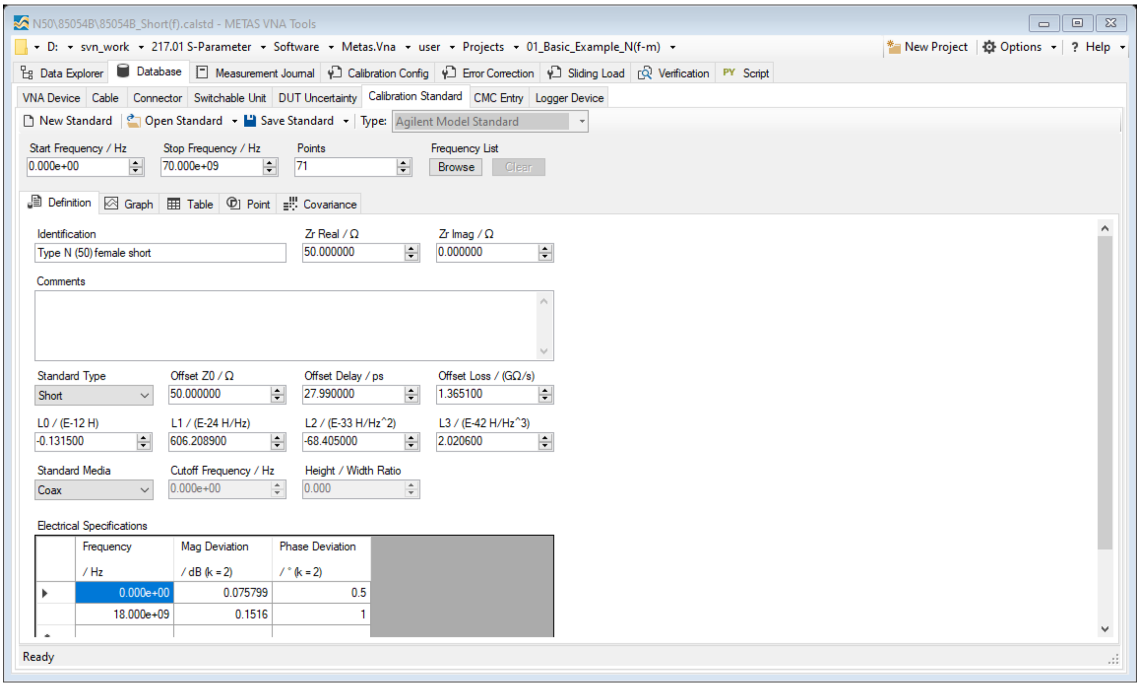

Figure 25: Database / Calibration Standard

New Standard creates a new database item of the type calibration standard (shortcut: Ctrl + N). For a databased standard see section 4.6.3.

Open Standard loads a calibration standard from a file (*.calstd), (shortcut: Ctrl + O).

Save Standard saves the calibration standard to a file (*.calstd), (shortcut: Ctrl + S).

Start Frequency / Hz specifies the start frequency.

Stop Frequency / Hz specifies the stop frequency.

Points sets the number of data points.

Frequency List Browse loads a frequency list.

Frequency List Clear clears the frequency list.

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

4.6.1 Agilent Model Standard

For a calibration standard of the type Agilent model the following controls are available:

Standard Type specifies the standard type as open, short, load or delay/thru.

Offset Z0 / Ω sets the offset line impedance in Ohm.

Offset Delay / ps sets the offset line delay in ps.

Offset Loss / (GΩ/s) set the offset line loss in GOhm/s.

CO / (E-15 F) sets the first polynomial coefficient for an open.

C1 / (E-27 F/Hz) sets the second polynomial coefficient for an open.

C2 / (E-36 F/Hzˆ2) sets the third polynomial coefficient for an open.

C3 / (E-45 F/Hzˆ3) sets the fourth polynomial coefficient for an open.

L0 / (E-12 H) sets the first polynomial coefficient for a short.

L1 / (E-24 H/Hz) sets the second polynomial coefficient for a short.

L2 / (E-33 H/Hzˆ2) sets the third polynomial coefficient for a short.

L3 / (E-42 H/Hzˆ3) sets the fourth polynomial coefficient for a short.

Standard Media specifies the standard media as coax or waveguide.

Cutoff Frequency / Hz specifies the waveguide cutoff frequency in Hz.

Height / Width Ratio specifies the waveguide height / width ratio (default: 0.5).

Electrical Specifications is a table with the following columns for an open or a short:

- Frequency in Hz
- Mag Deviation in dB with $k = 2$
- Phase Deviation in deg with $k = 2$

For a load the table has the following columns:

- Frequency in Hz
- Return Loss in dB with $k = 2$

E.g. an uncertainty of the Return Loss of -40 dB is translated to an uncertainty of 0.01 of real and imaginary part of the reflection coefficient.

For a delay/thru the table has the following columns:

- Frequency in Hz
- Reflection Return Loss in dB with $k = 2$
- Transmission Mag Deviation in dB with $k = 2$
- Transmission Phase Deviation in deg with $k = 2$

4.6.2 Databased Standard

Databased standards define the value and uncertainty budget of each frequency point and parameter. This format works without loss of accuracy. Thus it is ideal for transferring measurement data and uncertainties from National Metrology Institutes and accredited laboratories to customers. For a databased standard the following control is available:

Data Path specifies the file path (*.sdatb) which contains the S-parameters of the standard.

4.6.3 New Databased Standard Wizard

The wizard called New Databased Standard is designed to create a new databased standard, see figure 26. The following user controls are available:

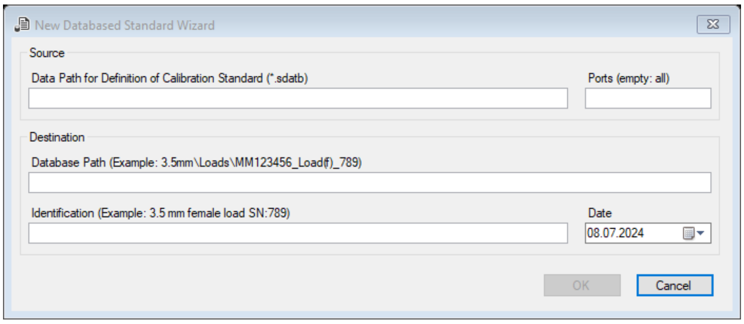

Figure 26: Database / New Databased Standard Wizard

Data Path for Definition of Calibration Standard specifies the source file (*.sdatb) for the definition of the calibration standard.

Ports specifies which ports of the definition of the calibration standard are used (empty: all).

Database Path specifies the destination in the database
(Example: 3.5mm\Loads\MM123456_Load(f)_789).

Identification field can contain an identification string
(Example: 3.5 mm female load SN:789).

Date sets the date. This date is part of the name of the databased standard.

4.6.4 Primary Airline Standard

For a primary airline standard the following controls are available:

Material Parameters specifies the following parameters:

- **Relative Permittivity of Air** specifies the value and the uncertainty ($k = 2$) of the relative permittivity of air.
- **Relative Permeability of Air** specifies the value and the uncertainty ($k = 2$) of the relative permeability of air.

DC Conductivity of Metal / (S/m) specifies the value and the uncertainty ($k = 2$) of the DC conductivity of metal in S/m.

HF Conductivity of Metal / (S/m/GHzˆ0.5) specifies the value and the uncertainty ($k = 2$) of the HF conductivity of metal in S/m/GHzˆ0.5.

Misc specifies the following parameter:

Line Shift / m specifies the value and the uncertainty ($k = 2$) of the distance in m which the reference planes of the standard definition are shifted with respect to the calibration reference planes. If the reference plane at port 1 of the standard definition is behind the calibration reference plane (this means towards the VNA) then the value is negative. For the opposite shift it would be positive and for no shift it is zero.

Connector 1 specifies the gender and the mechanical dimensions of the connector 1. The following controls are are available:

Gender specifies the gender (female, male or none) of the connector.

Pin Depth / m sets the value and uncertainty ($k = 2$) of the pin depth of the standard in m.

Pin Gap / m sets the value and uncertainty ($k = 2$) of the pin gap used for the simulation of the connector in m.

Female Outer Chamfer / m sets the value and uncertainty ($k = 2$) of the outer chamfer for a female connector in m.

Female Inner Chamfer / m sets the value and uncertainty ($k = 2$) of the inner chamfer for a female connector in m.

Male Outer Chamfer / m sets the value and uncertainty ($k = 2$) of the outer chamfer for a male connector in m.

Male Inner Chamfer / m sets the value and uncertainty ($k = 2$) of the inner chamfer for a male connector in m.

Pin Diameter / m sets the value and uncertainty ($k = 2$) of the pin diameter in m. For a female connector this should be set to the nominal value of the connector family.

Hole Diameter / m sets the value and uncertainty ($k = 2$) of the hole diameter in m. For a male connector this should be set to the value of the pin diameter.

OC Diameter / m sets the value and uncertainty ($k = 2$) of the outer conductor diameter in m. This should be set to the nominal value of the connector family.

Male CC Diameter / m sets the value and uncertainty ($k = 2$) of the diameter of the male center conductor in m. For a female connector this should be set to the nominal value of the connector family.

Number of Slots specifies the number of slots. Zero means slotless.

Slotless Hole Length / m sets the value and uncertainty ($k = 2$) of the hole length in m for a slotless female connector.

Slotless Female CC Diameter / m sets the value and uncertainty ($k = 2$) of the center conductor diameter in m for a slotless female connector. For a male connector this should be set to the nominal value of the connector family.

Slot Length / m sets the value and uncertainty ($k = 2$) of the slot length in m for a slotted female connector. The slot length must be a multiple of the length of a single line section.

Slot Width / m sets the value and uncertainty ($k = 2$) of the slot width in m for a slotted female connector.

Slot Chamfer / m sets the value and uncertainty ($k = 2$) of the slot chamfer in m for a slotted female connector.

Line Section specifies the length of the standard and the diameter profile of the line section. The following controls are available:

Length / m specifies the value and the uncertainty ($k = 2$) of the distance between the reference planes of connector 1 and 2.

Variable Gamma specifies if gamma is variable.

Table Diameter Profile is a table with the following columns:

- z-Position in m
- U(z-Position) in m with $k = 2$
- ICOD in m
- U(ICOD) in m with $k = 2$
- OCID in m
- U(OCID) in m with $k = 2$

Graph Diameter Profile shows a graphical visualization of the diameter profiles.

Connector 2 specifies the gender and the mechanical dimensions of the connector 2. For the available controls see Connector 1.

For a primary airline standard the following precomputed data is needed, see figure 27.

```
Database/CalibrationStandards/[ConnectorFamily]/Primary/[name]
├── [name].calstd ........ primary airline standard
└── data ................. directory for precomputed S-parameter data
    ├── [name]_c1.sdatb .... simulated connector (female-male) at port 1
    ├── [name]_c2.sdatb .... simulated connector (female-male) at port 2
    ├── [name]_k1.sdatb .... kapton or adapter effect on port 1 (optional)
    ├── [name]_k2.sdatb .... kapton or adapter effect on port 2 (optional)
    ├── [name]_pg1.sdatb ... simulated nominal pin gap (10 µm) at port 1
    └── [name]_pg2.sdatb ... simulated nominal pin gap (10 µm) at port 2
```

Figure 27: Precomputed data for a primary airline standard

4.6.5 Primary Offset Short Standard

For a primary offset short standard the following controls are available:

Material Parameters specifies the material parameters.

Connector specifies the gender and the mechanical dimensions of the connector.

Line Section specifies the length between the reference plane in the connector and the short plane. The diameter profile of the line section is specified as well.

For more details, see section 4.6.4. For a primary offset short the following precomputed data is needed, see figure 28.

```
Database/CalibrationStandards/[ConnectorFamily]/Primary/[name]
├── [name].calstd ........................ primary offset short standard
└── data ................................. directory for precomputed S-parameter data
    ├── [name]_c1.sdatb .................. simulated connector (female-male)
    ├── [name]_k1.sdatb .................. kapton or adapter effect (optional)
    └── [name]_pg1.sdatb ................. simulated nominal pin gap (10 µm)
```

Figure 28: Precomputed data for a primary offset short standard

4.6.6 Waveguide Shim Standard

For a waveguide shim standard the following controls are available:

Material Parameters specifies the following parameters:

- **Relative Permittivity of Air** specifies the value and the uncertainty ($k = 2$) of the relative permittivity of air.
- **Relative Permeability of Air** specifies the value and the uncertainty ($k = 2$) of the relative permeability of air.
- **DC Conductivity of Metal / (S/m)** specifies the value and the uncertainty ($k = 2$) of the DC conductivity of metal in S/m.
- **HF Conductivity of Metal / (S/m/GHzˆ0.5)** specifies the value and the uncertainty ($k = 2$) of the HF conductivity of metal in S/m/GHzˆ0.5.

Waveguide Connector 1 specifies the mechanical dimensions of the connector 1. The following controls are are available:

- **Test Port Width / m** specifies the nominal width of the test port in m.
- **Test Port Height / m** specifies the nominal height of the test port in m.

Waveguide Shim Section specifies the length of the standard and the mechanical dimensions of the shim section. The following controls are available:

- **Length / m** sets the value and the uncertainty ($k = 2$) of the length of the shim section in m.
- **Width / m** sets the value and the uncertainty ($k = 2$) of the width of the shim section in m.
- **Height / m** sets the value and the uncertainty ($k = 2$) of the height of the shim section in m.

Radius / m sets the value and the uncertainty ($k = 2$) of the radius of the shim section in m.

Width Offset / m sets the value and the uncertainty ($k = 2$) of the width offset of the shim section in m.

Height Offset / m sets the value and the uncertainty ($k = 2$) of the height offset of the shim section in m.

Waveguide Connector 2 specifies the mechanical dimensions of the connector 2. For the available controls see Waveguide Connector 1.

4.6.7 Waveguide Offset Short Standard

For a waveguide offset short standard the following controls are available:

Material Parameters specifies the material parameters.

Waveguide Connector specifies the mechanical dimensions of the connector.

Waveguide Shim Section specifies the length between the reference plane in the connector and the short plane. The mechanical dimensions of the shim section are specified as well.

For more details, see section 4.6.6.

4.6.8 Simple Line Standard

For a simple line standard the following controls are available:

Length / m sets the value and the uncertainty ($k = 2$) of the length of the line in m.

Relative Permittivity specifies the value and the uncertainty ($k = 2$) of the relative permittivity.

Variable Gamma specifies if γ is variable.

Admittance List is a table with the following columns:

- Frequency in Hz
- G in S/m
- U(G) in S/m with $k = 2$
- C in F/m
- U(C) in F/m with $k = 2$

4.6.9 On-Wafer Line Standard

For an on-wafer line standard the following controls are available:

Length / m sets the value and the uncertainty ($k = 2$) of the length of the line in m.

Width of Ground Conductor / m sets the value and the uncertainty ($k = 2$) of the width of the ground conductor in m.

Width of Signal Conductor / m sets the value and the uncertainty ($k = 2$) of the width of the signal conductor in m.

Gap Width / m sets the value and the uncertainty ($k = 2$) of the gap width in m.

Conductor Thickness / m sets the value and the uncertainty ($k = 2$) of the conductor thickness in m.

Surface Roughness / m sets the value and the uncertainty ($k = 2$) of the surface roughness in m.

Variable Gamma specifies if γ is variable.

Model Version specifies the version of the used model. The following versions are available:

- Heinrich Paper 1993
- Fortran Code 1993 (default)
- Schnieder Paper 2003
- Gold Paper 2019
- Phung Paper 2021

Material Parameters is a table with the following columns:

- Frequency in Hz
- Conductivity in S/m
- U(Conductivity) in S/m with $k = 2$
- Relative Permittivity
- U(Relative Permittivity) with $k = 2$
- Tan delta
- U(Tan delta) with $k = 2$

4.6.10 On-Wafer Offset Short Standard

For an on-wafer offset short standard the following controls are available:

Length / m sets the value and the uncertainty ($k = 2$) of the length of the offset line in m.

Width of Ground Conductor / m sets the value and the uncertainty ($k = 2$) of the width of the ground conductor in m.

Width of Signal Conductor / m sets the value and the uncertainty ($k = 2$) of the width of the signal conductor in m.

Gap Width / m sets the value and the uncertainty ($k = 2$) of the gap width in m.

Conductor Thickness / m sets the value and the uncertainty ($k = 2$) of the conductor thickness in m.

Surface Roughness / m sets the value and the uncertainty ($k = 2$) of the surface roughness in m.

Variable Length specifies if the length is variable.

Model Version specifies the version of the used model. The following versions are available:

- Heinrich Paper 1993
- Fortran Code 1993 (default)
- Schnieder Paper 2003
- Gold 2019
- Phung Paper 2020

Material Parameters is a table with the following columns:

- Frequency in Hz
- Conductivity in S/m
- U(Conductivity) in S/m with $k = 2$
- Relative Permittivity
- U(Relative Permittivity) with $k = 2$
- Tan delta
- U(Tan delta) with $k = 2$

4.6.11 Power Sensor Table Standard

For a power sensor table standard the following controls are available:

Driver sets the driver for the communication with the power sensor.

Resource sets the VISA resource name of the power sensor.

Channel sets the channel (default: 1) of the power meter to which the power sensor is connected to.

Default Frequency sets the default frequency (default: 50 MHz) of the power sensor in Hz.

Data Table is a table with the following columns:

- Frequency in Hz
- Reflection Coefficient Real

- U(Reflection Coefficient Real) with $k = 2$
- Reflection Coefficient Imag
- U(Reflection Coefficient Imag) with $k = 2$
- Calibration Factor in W/W
- U(Calibration Factor) in W/W with $k = 2$

Uncertainties specifies the absolute and relative uncertainties of the power sensor. The following controls are available for the absolute uncertainties:

Measurement Noise / W sets the uncertainty ($k = 2$) of the measurement noise in W.

Noise Filter specifies the noise filter used for the measurement noise specification above.

Zero Offset / W sets the uncertainty ($k = 2$) of the zero offset in W.

Zero Drift / W sets the uncertainty ($k = 2$) of the zero drift in W.

The following controls are available for the relative uncertainties:

Aging Freq Corr / (W/W) sets the uncertainty ($k = 2$) of the aging, which is correlated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements before and after an external calibration.

Aging Freq Uncorr / (W/W) sets the uncertainty ($k = 2$) of the aging, which is uncorrelated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements before and after an external calibration.

Drift Freq Corr / (W/W) sets the uncertainty ($k = 2$) of the drift, which is correlated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements over a longer time period.

Drift Freq Uncorr / (W/W) sets the uncertainty ($k = 2$) of the drift, which is uncorrelated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements over a longer time period.

Linearity / (W/W) sets the uncertainty ($k = 2$) of the linearity in W/W.

Power Meter / (W/W) sets the uncertainty ($k = 2$) of the power meter in W/W.

Repeatability / (W/W) sets the uncertainty ($k = 2$) of the repeatability in W/W. This uncertainty covers the observed difference due new connections.

Temperature / (W/W) sets the uncertainty ($k = 2$) of the temperature in W/W.

4.6.12 Power Sensor Databased Standard

For a power sensor databased standard the following controls are available:

Driver sets the driver for the communication with the power sensor.

Resource sets the VISA resource name of the power sensor.

Channel sets the channel (default: 1) of the power meter to which the power sensor is connected to.

Default Frequency sets the default frequency (default: 50 MHz) of the power sensor in Hz.

Data Path specifies the file path (*.sdatb) which contains the following S-parameters of the power sensor standard:

S1,1 is the reflection coefficient of the power sensor.

S2,1 is the square root of the calibration factor.

S1,2 is zero.

S2,2 is zero.

Uncertainties specifies the absolute and relative uncertainties of the power sensor. For the available controls see section 4.6.11.

4.6.13 Cascaded Power Sensor Standard

For a cascaded power sensor standard the following controls are available:

Driver shows the driver for the communication with the power sensor.

Resource shows the VISA resource name of the power sensor.

Adapter Path specifies the file path (*.calstd) which contains the S-parameters of the adapter.

Power Sensor Path specifies the file path (*.calstd) of the power sensor standard.

4.6.14 Spectrum Analyzer Table Standard

For a spectrum analyzer table standard the following controls are available:

Driver sets the driver for the communication with the spectrum analyzer.

Resource sets the VISA resource name of the spectrum analyzer.

Data Table is a table with the following columns:

- Frequency in Hz
- Reflection Coefficient Real
- U(Reflection Coefficient Real) with $k = 2$
- Reflection Coefficient Imag
- U(Reflection Coefficient Imag) with $k = 2$
- Calibration Factor in W/W
- U(Calibration Factor) in W/W with $k = 2$

Uncertainties specifies the absolute and relative uncertainties of the spectrum analyzer. The following controls are available for the absolute uncertainties:

Measurement Noise / W sets the uncertainty ($k = 2$) of the measurement noise in W.

Resolution BW Setting / Hz specifies the resolution bandwidth in Hz used for the measurement noise specification above.

The following controls are available for the relative uncertainties:

Aging Freq Corr / (W/W) sets the uncertainty ($k = 2$) of the aging, which is correlated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements before and after an external calibration.

Aging Freq Uncorr / (W/W) sets the uncertainty ($k = 2$) of the aging, which is uncorrelated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements before and after an external calibration.

Drift Freq Corr / (W/W) sets the uncertainty ($k = 2$) of the drift, which is correlated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements over a longer time period.

Drift Freq Uncorr / (W/W) sets the uncertainty ($k = 2$) of the drift, which is uncorrelated over frequency, in W/W. This uncertainty covers the observed difference of own verification measurements over a longer time period.

Linearity / (W/W) sets the uncertainty ($k = 2$) of the linearity in W/W.

Repeatability / (W/W) sets the uncertainty ($k = 2$) of the repeatability in W/W. This uncertainty covers the observed difference due new connections.

Temperature / (W/W) sets the uncertainty ($k = 2$) of the temperature in W/W.

4.6.15 Spectrum Analyzer Databased Standard

For a spectrum analyzer databased standard the following controls are available:

Driver sets the driver for the communication with the spectrum analyzer.

Resource sets the VISA resource name of the spectrum analyzer.

Data Path specifies the file path (*.sdatb) which contains the following S-parameters of the spectrum analyzer standard:

S1,1 is the reflection coefficient of the spectrum analyzer.

S2,1 is the square root of the calibration factor.

S1,2 is zero.

S2,2 is zero.

Uncertainties specifies the absolute and relative uncertainties of the spectrum analyzer. For the available controls see section 4.6.14.

4.6.16 Cascaded Spectrum Analyzer Standard

For a cascaded spectrum analyzer standard the following controls are available:

Driver shows the driver for the communication with the spectrum analyzer.

Resource shows the VISA resource name of the spectrum analyzer.

Adapter Path specifies the file path (*.calstd) which contains the S-parameters of the adapter.

Spectrum Analyzer Path specifies the file path (*.calstd) of the spectrum analyzer standard.

4.7 CMC Entry

The tabular page, called CMC Entry, is designed to specify Calibration and Measurement Capabilities (CMCs) in the database, see figure 29. The following user controls are available:

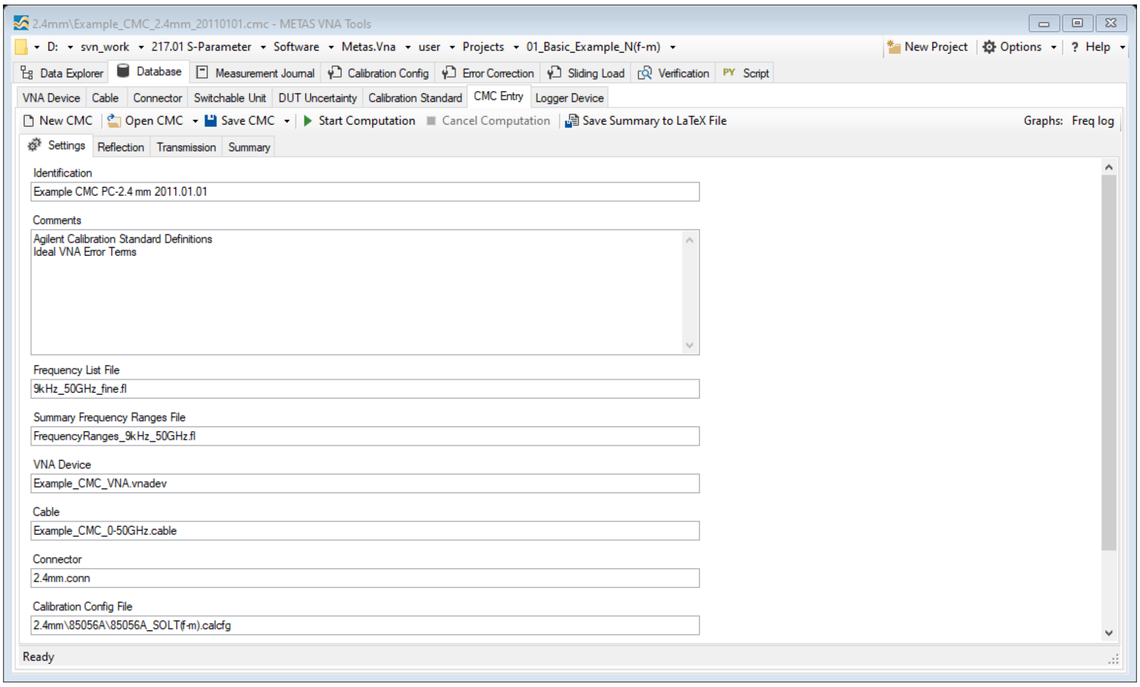

Figure 29: Database / CMC Entry / Settings

New CMC creates a new database item of the type CMC entry (shortcut: Ctrl + N).

Open CMC loads a CMC entry from a file (*.cmc), (shortcut: Ctrl + O).

Save CMC saves the CMC entry to a file (*.cmc), (shortcut: Ctrl + S).

Start Computation computes the CMC reflection and transmission tables (shortcut: Ctrl + R).

Cancel Computation cancels the computation (shortcut: Ctrl + T).

Save Summary to LaTeX File saves summary to a LaTeX file (*.tex).

Freq log sets the frequency axis to linear or logarithmic (default: Freq lin).

The following user controls are available on the sub tabular page called Settings:

Identification field can contain an identification string.

Comments field can contain user comments.

Frequency List File sets the path (*.fl) for the frequency list.

Summary Frequency Ranges File sets the path (*.fl) for the frequency ranges used in the summary.

VNA Device specifies the VNA device (*.vnadev).

Cable specifies the cable (*.cable).

Connector specifies the connector (*.conn).

Calibration Config File specifies the calibration configuration (*.calcfg).

VNA Error Terms specifies the VNA error terms (*.calb) used to generate raw data. For an ideal VNA do not select a file.

Numeric Format Mag Reflection sets the numeric format of the magnitude of the reflection (default: f3).

Numeric Format Mag Transmission sets the numeric format of the magnitude of the transmission in dB (default: f2).

Numeric Format Phase sets the numeric format of the phase of the reflection and transmission in deg (default: f1).

Calculation Mode sets the calculation mode to min, mean or max.

The next sub tabular page is called Reflection, see figure 30. The left part of the page is used to specify the different reflection levels (default: 0 to 1.0 in 0.1 steps) and the number of phase positions (default: 24). The right part of the page contains a table with the following columns:

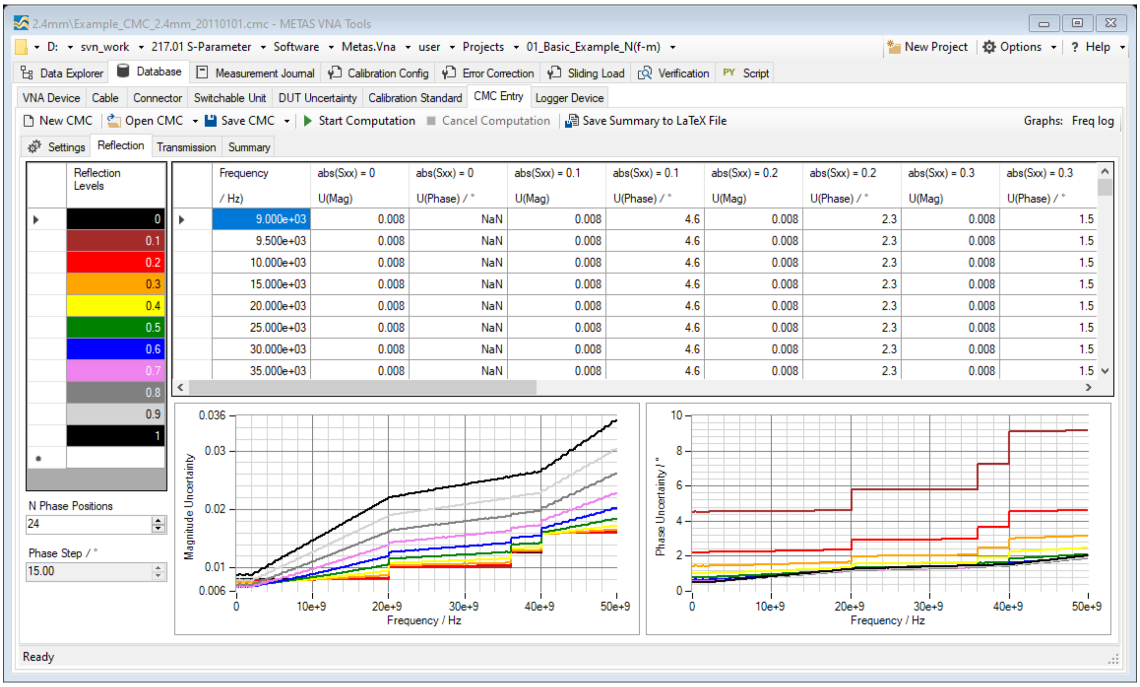

Figure 30: Database / CMC Entry / Reflection

- Frequency in Hz

- Magnitude Uncertainty with $k = 2$, one column for each reflection level
- Phase Uncertainty in deg with $k = 2$, one column for each reflection level

The next sub tabular page is called Transmission, see figure 31. The left part of the page is used to specify the different transmission levels in dB (default: 0 dB, -3 dB, -6 dB and -10 dB to -60 dB in -10 dB steps), the magnitude of the reflection (default: 0) and the number of phase positions (default: 8). The right part of the page contains a table with the following columns:

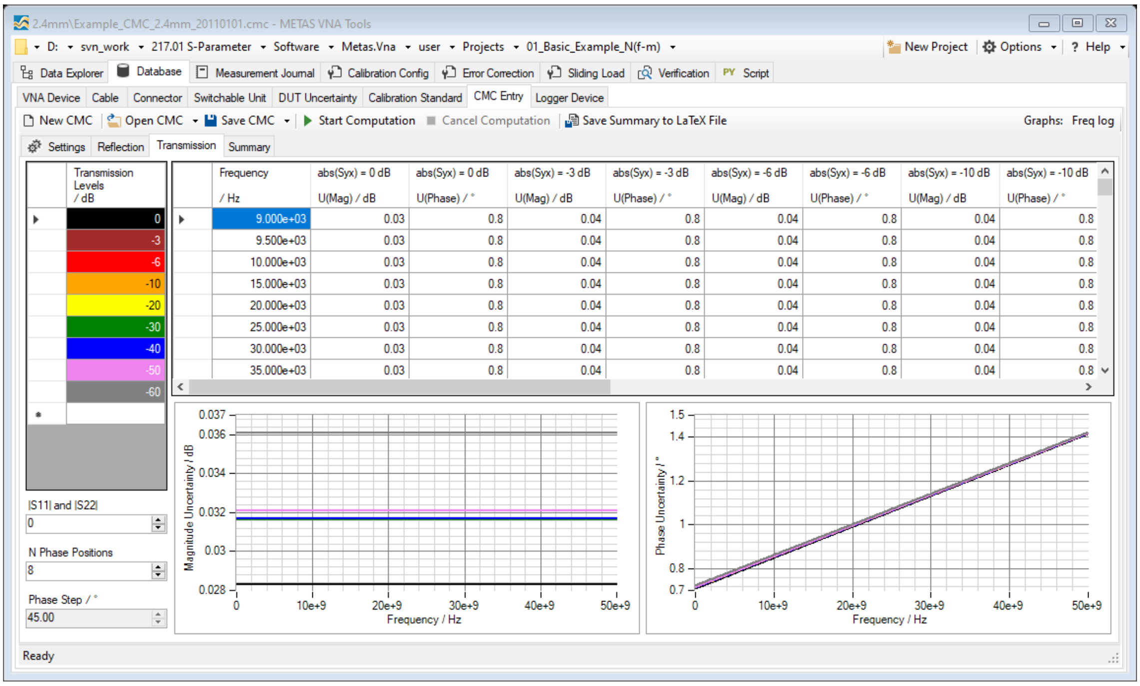

Figure 31: Database / CMC Entry / Transmission

- Frequency in Hz
- Magnitude Uncertainty in dB with $k = 2$, one column for each transmission level
- Phase Uncertainty in deg with $k = 2$, one column for each transmission level

The next sub tabular page is called Summary, see figure 32. It contains four tables which summarizes the CMC entry for the given frequency ranges.

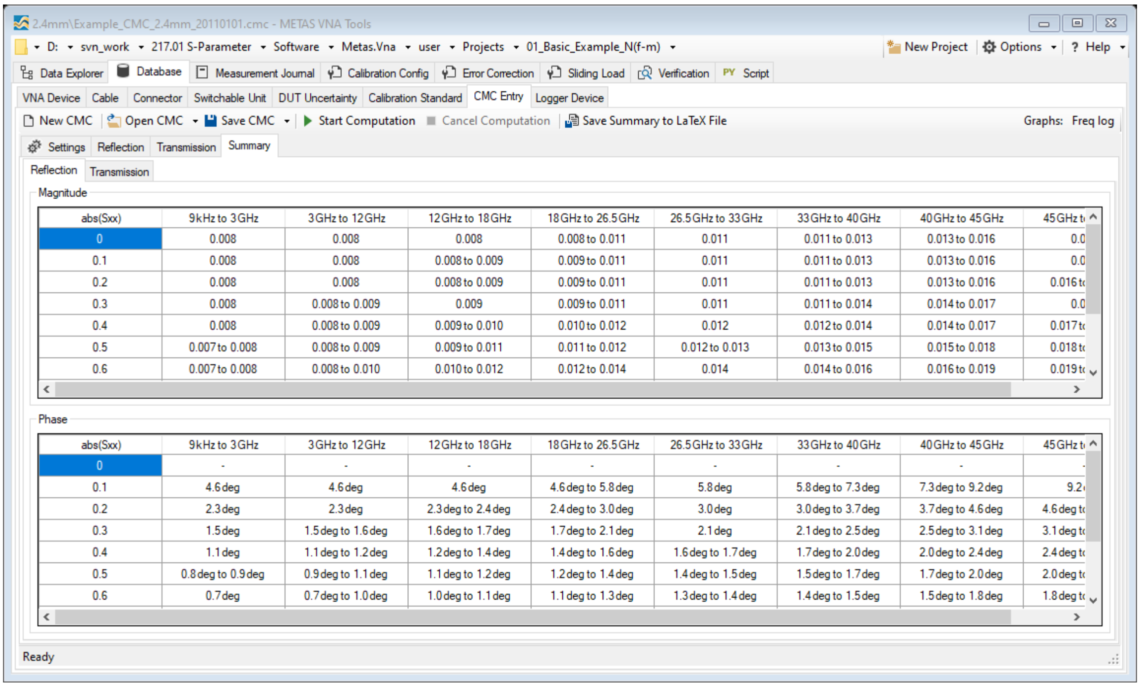

Figure 32: Database / CMC Entry / Summary

4.8 Logger Device

The tabular page, called Logger Device, is designed to specify logger devices in the database, see figure 33. The following user controls are available:

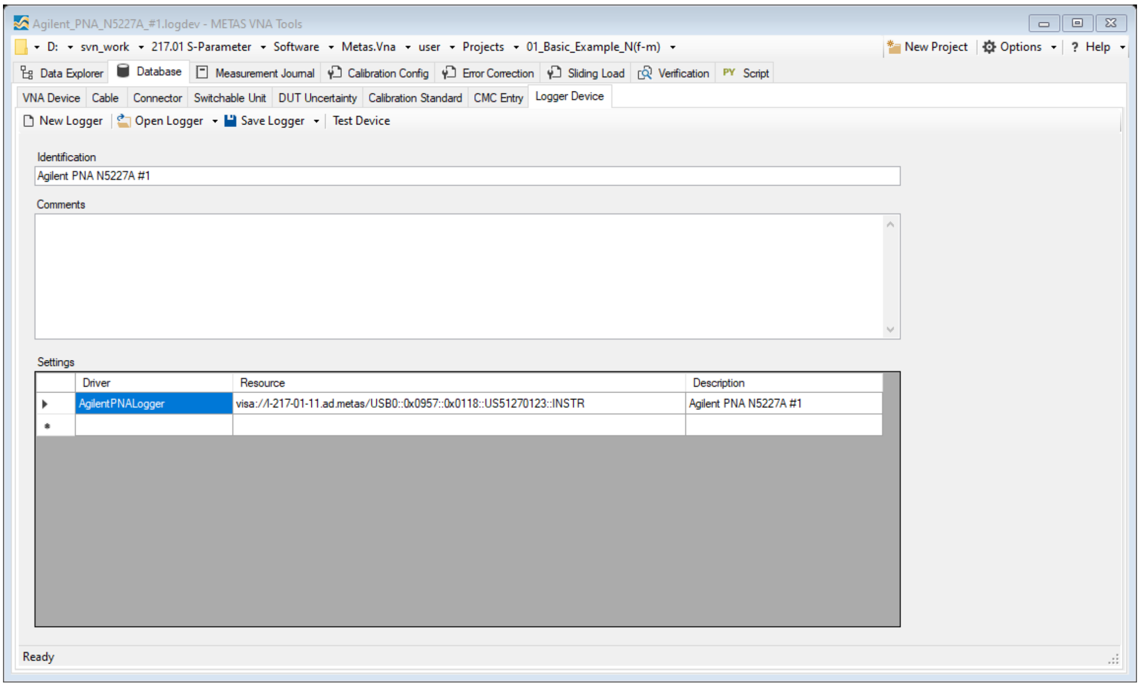

Figure 33: Database / Logger Device

New Logger creates a new database item of the type logger device (shortcut: Ctrl + N).

Open Logger loads a logger item from a file (*.logdev), (shortcut: Ctrl + O).

Save Logger saves the logger item to a file (*.logdev), (shortcut: Ctrl + S).

Test Device tests logger device if connection is possible.

Identification field can contain an identification string.

Comments field can contain user comments.

Settings is a table with the following columns:

- **Driver** sets the driver for the communication with the logger device.
- **Resource** sets the resource name of the logger device.
- **Description** field can contain a description.

5 Measurement Journal

The tabular page, called Measurement Journal, is designed to collect measurement data and to protocol the measurement process, see figure 34. The following user controls are available:

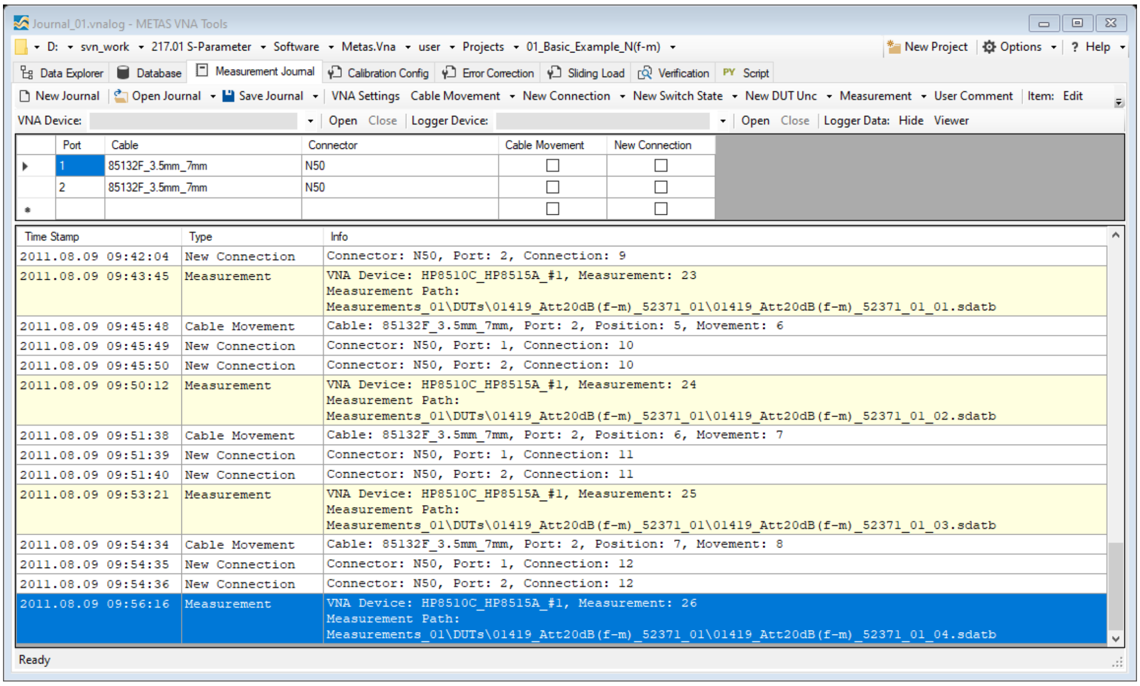

Figure 34: Measurement Journal

New Journal creates a new measurement journal (shortcut: Ctrl + N).

Open Journal loads an existing measurement journal from a file (*.vnalog), (shortcut: Ctrl + O).

Save Journal saves the measurement journal to a file (*.vnalog), (shortcut: Ctrl + S).

Auto Save enables or disables auto save of the measurement journal.

VNA Settings adds a journal item for VNA settings to the measurement journal, see 5.1.

Cable Movement adds a journal item for cable movement to the measurement journal, see 5.2.

Custom Cable Settings specifies a cable for the current journal which is not in the database, see 5.3.

New Connection adds a journal item for a new connection to the measurement journal, see 5.4.

Custom Connector Settings specifies a connector for the current journal which is not in the database, see 5.5.

New DUT Unc adds a journal item for a new DUT uncertainty to the measurement journal, see 5.8.

Custom DUT Uncertainty Settings specifies a DUT uncertainty for the current journal which is not in the database, see 5.9.

Measurement adds a measurement entry to the journal, see 5.10.

Begin Experiment defines the start of an experiment, see 5.11.

End Experiment defines the end of an experiment.

Measurement Series adds an entry for a series of measurements to the journal (shortcut: Ctrl + M), see 5.12.

Measurement Last Setup adds a measurement entry to the journal using the last VNA setup (shortcut: Ctrl + L).

Power Sensor adds an entry for a measurement of a power sensor (shortcut: Ctrl + P), see 5.13.

User Comment adds a user comment to the measurement journal, see 5.16.

Edit shows the selected item of the journal.

Rename renames the selected measurement item of the journal.

Delete deletes the selected items of the journal.

VNA Device selects a VNA device.

Open opens the VISA connection to the VNA device.

Close closes the VISA connection to the VNA device.

Logger Device selects a logger device.

Open opens the connection to the logger device.

Close closes the connection to the logger device.

Logger Data Hide hides the logger entries in the journal.

Logger Data Viewer shows the logger data viewer.

Cable and Connector Table specifies the test port cable and connector for each port.

- **Cable movement** adds one or multiple entries in the measurement journal for cable movements at the selected ports before the measurement.
- **New connection** adds one or multiple entries in the measurement journal for new connections at the selected ports before the measurement.

5.1 VNA Settings

The dialog, called VNA Settings, is designed to set up the VNA, see figure 35. The following

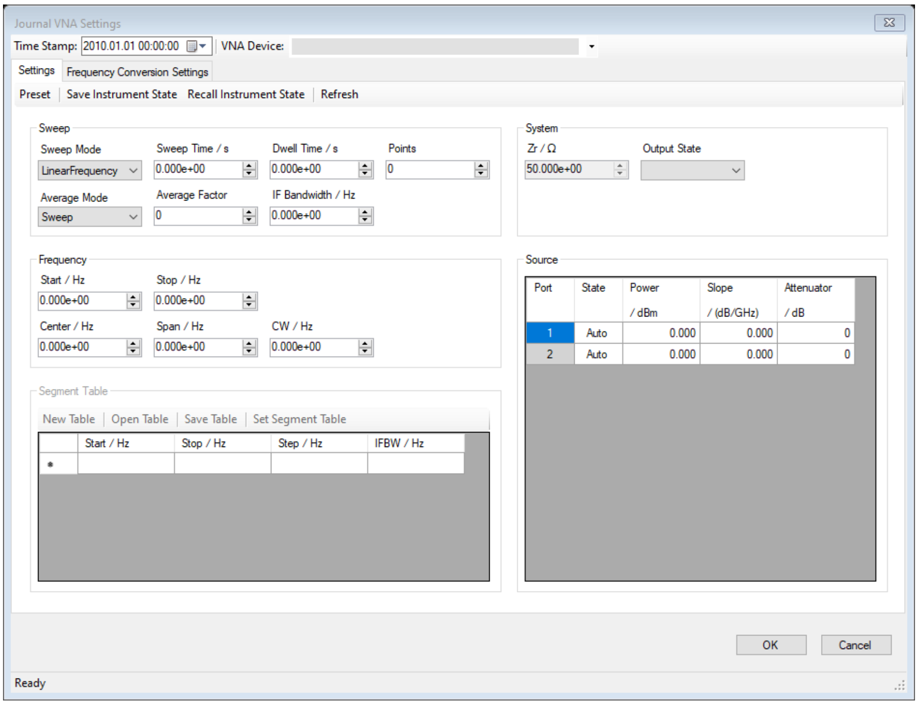

Figure 35: Measurement Journal / VNA Settings

user controls are available:

Time Stamp specifies the time stamp for the journal item.

VNA Device specifies the VNA device.

The following user controls are available in the tabular page called Settings:

Preset presets the VNA.

Save Instrument State saves the instrument state from the VNA to a file (*.is).

Recall Instrument State recalls the instrument state from a file (*.is) to the VNA.

Refresh refreshes all settings from the VNA.

Sweep Mode sets the sweep mode to linear frequency, log frequency, segment sweep or CW time.

Sweep Time / s sets the sweep time in s.

Dwell Time / s sets the dwell time in s.

Points sets the number of sweep points.

Average Mode sets the average mode to sweep or point.

Average Factor sets the average factor.

IF Bandwidth / Hz sets the IF bandwidth in Hz.

Start Frequency / Hz sets the start frequency in Hz.

Stop Frequency / Hz sets the stop frequency in Hz.

Center Frequency / Hz sets the center frequency in Hz.

Frequency Span / Hz sets the frequency span in Hz.

CW Frequency / Hz sets the frequency for CW sweep mode in Hz.

New Table creates a new segment table.

Open Table loads a segment table from a file (*.txt).

Save Table saves the segment table to a file (*.txt).

Set Segment Table sets the segment table to the VNA.

Segment Table is a table with the following columns:

- Start Frequency in Hz
- Stop Frequency in Hz
- Step Size in Hz
- IF Bandwidth in Hz

System Zr / Ω shows the reference impedance in Ohm. To specify the reference impedance of the VNA device see section 4.1.

Output State turns RF power from the source ON or OFF.

Source is a table with the following columns:

State sets the source state of the port to:

Auto turns the source power on when required for a measurement.
On turns the source power always on regardless of the measurement.
Off turns source power always off regardless of the measurement.

Power / dBm sets the source power level of the port in dBm.

Slope / (dB/GHz) sets the source slope of the port in dB/GHz.

Attenuator / dB sets the attenuation of the port in dB.

The following user controls are available in the tabular page called Frequency Conversion Settings:

Simple View shows the simple table for frequency conversion where the receiver and source frequencies are equal.

Advanced View shows the advanced table for frequency conversion where the receiver and source frequencies are not equal.

State Off turns frequency conversion off.

State On turns frequency conversion on.

Refresh refreshes frequency conversion settings from the VNA.

Simple Table is a table with the following columns:

- Port
- Frequency Numerator in Hz/Hz
- Frequency Denominator in Hz/Hz
- Frequency Offset in Hz
- Frequency Information

Advanced Table is a table with the following columns:

- Port
- Test Receiver Frequency Numerator in Hz/Hz
- Test Receiver Frequency Denominator in Hz/Hz
- Test Receiver Frequency Offset in Hz
- Test Receiver Frequency Information
- Reference Receiver Frequency Numerator in Hz/Hz
- Reference Receiver Frequency Denominator in Hz/Hz
- Reference Receiver Frequency Offset in Hz
- Reference Receiver Frequency Information
- Source Frequency Numerator in Hz/Hz
- Source Frequency Denominator in Hz/Hz
- Source Frequency Offset in Hz
- Source Frequency Information

5.2 Cable Movement

The dialog, called Cable Movement, is designed to describe a cable movement for the journal, see figure 36. The following user controls are available:

Time Stamp specifies the time stamp of the journal item.

Cable selects a cable from the database.

Port specifies at which port the cable was moved.

Position specifies the position of the cable. Thus each cable movement requires an increase of the position number. With each change of the position number the cable uncertainties, specified in the database, are added to the measurement data.

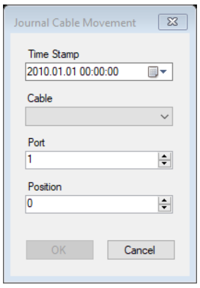

Figure 36: Measurement Journal / Cable Movement

5.3 Custom Cable Settings

The dialog, called Custom Cable Settings, is designed to describe cables which are not in the database for the current journal. One can specify the magnitude and phase stability of such a cable in this dialog, see figure 37. The following user controls are available:

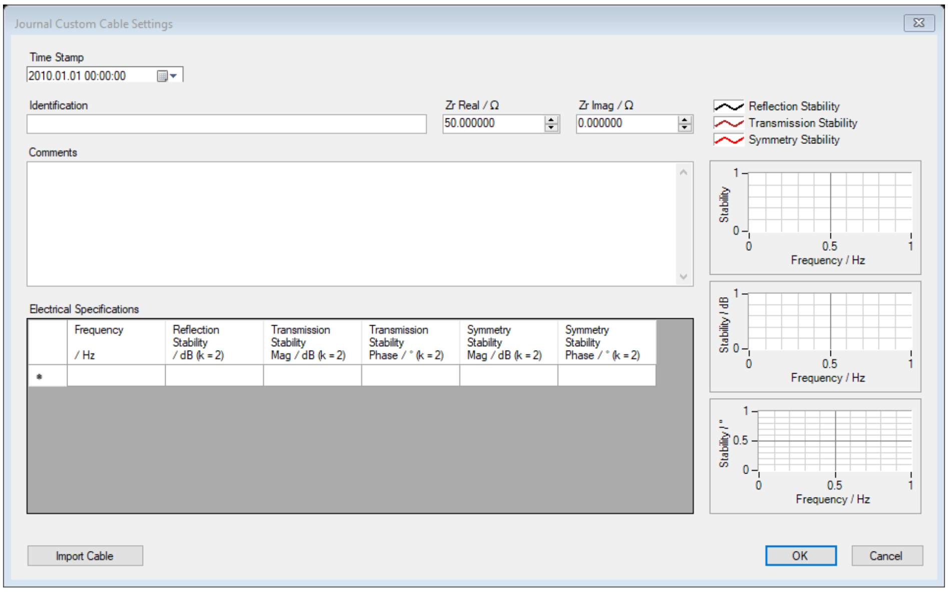

Figure 37: Measurement Journal / Custom Cable Settings

Time Stamp specifies the time stamp of the journal item.

Identification field contains identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz

- Reflection Stability in dB with $k = 2$
- Transmission Stability Mag in dB with $k = 2$
- Transmission Stability Phase in deg with $k = 2$
- Symmetry Stability Mag in dB with $k = 2$
- Symmetry Stability Phase in deg with $k = 2$

Import Cable imports a cable from the database.

5.4 New Connection

The dialog, called New Connection, is designed to describe a new connection in the journal, see figure 38. The following user controls are available:

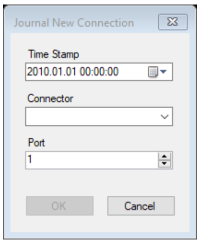

Figure 38: Measurement Journal / New Connection

Time Stamp specifies the time stamp of the journal item.

Connector selects a connector from the database.

Port specifies at which port the new connection was made.

5.5 Custom Connector Settings

The dialog, called Custom Connector Settings, is designed to describe a connector which is not in the database for the current journal. One can specify the repeatability of such a connector in this dialog, see figure 39. The following user controls are available:

Time Stamp specifies the time stamp of the journal item.

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz
- Reflection Repeatability in dB with $k = 2$

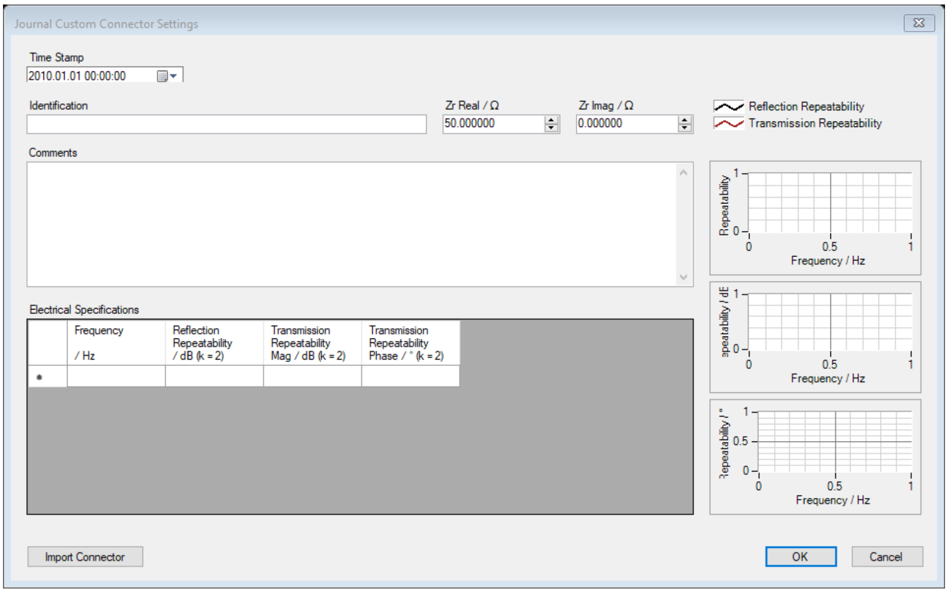

Figure 39: Measurement Journal / Custom Connector Settings

- Transmission Repeatability Mag in dB with $k = 2$
- Transmission Repeatability Phase in deg with $k = 2$

Import Connector imports a connector from the database.

5.6 New Switch State

The dialog, called New Switch State, is designed to describe a new switch state in the journal, see figure 40. The following user controls are available:

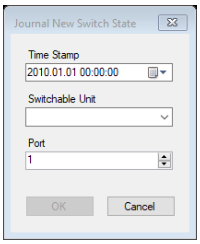

Figure 40: Measurement Journal / New Switch State

Time Stamp specifies the time stamp of the journal item.

Switchable Unit selects a switchable unit from the database. A switchable unit can be an electronic calibration unit (ECU), a step attenuator or any other switchable device under test (DUT).

Port specifies at which port the new switch state was made.

5.7 Custom Switchable Unit Settings

The dialog, called Custom Switchable Unit Settings, is designed to describe a switchable unit which is not in the database for the current journal. One can specify the repeatability of such a switchable unit in this dialog, see figure 41. The following user controls are available:

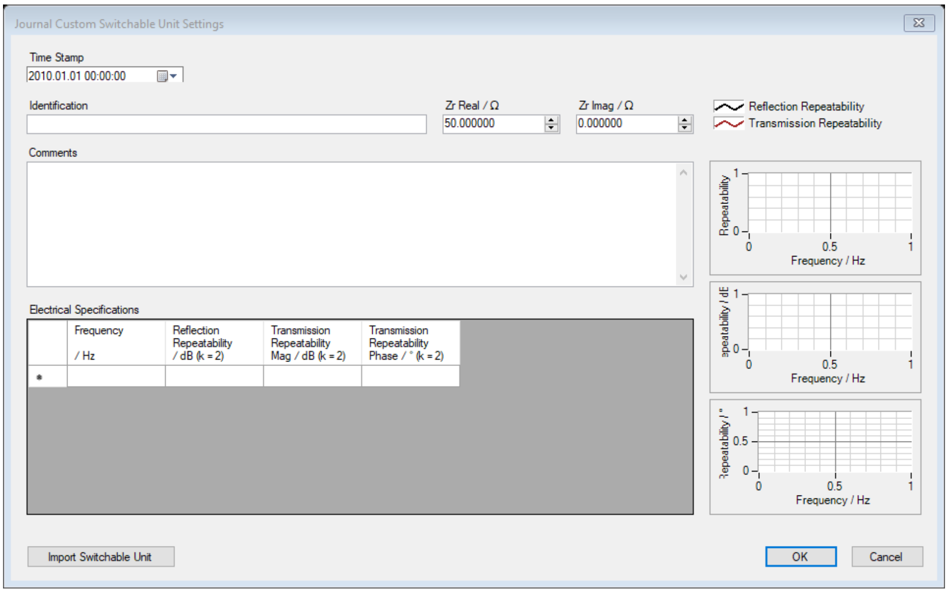

Figure 41: Measurement Journal / Custom Switchable Unit Settings

Time Stamp specifies the time stamp of the journal item.

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz
- Reflection Repeatability in dB with $k = 2$
- Transmission Repeatability Mag in dB with $k = 2$
- Transmission Repeatability Phase in deg with $k = 2$

Import Switchable Unit imports a switchable unit from the database.

5.8 New DUT Uncertainty

The dialog, called New DUT Uncertainty, is designed to select a new DUT uncertainty and to put it in the journal, see figure 42. The following user controls are available:

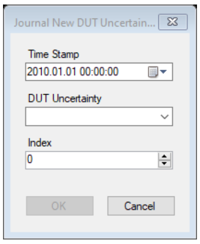

Figure 42: Measurement Journal / New Connection

Time Stamp specifies the time stamp of the journal item.

DUT Uncertainty selects a DUT uncertainty from the database.

Index specifies the DUT index.

The DUT uncertainty can be used to represent the crosstalk in on-wafer measurements. In this case the DUT uncertainty is uncorrelated for every standard on the wafer and it's correlated for multiple measurements of the same standard.

5.9 Custom DUT Uncertainty Settings

The dialog, called Custom DUT Uncertainty Settings, is designed to describe a DUT uncertainty which is not in the database and to put it in the current journal. One can specify the additional uncertainty of such a DUT in this dialog, see figure 43. The following user controls

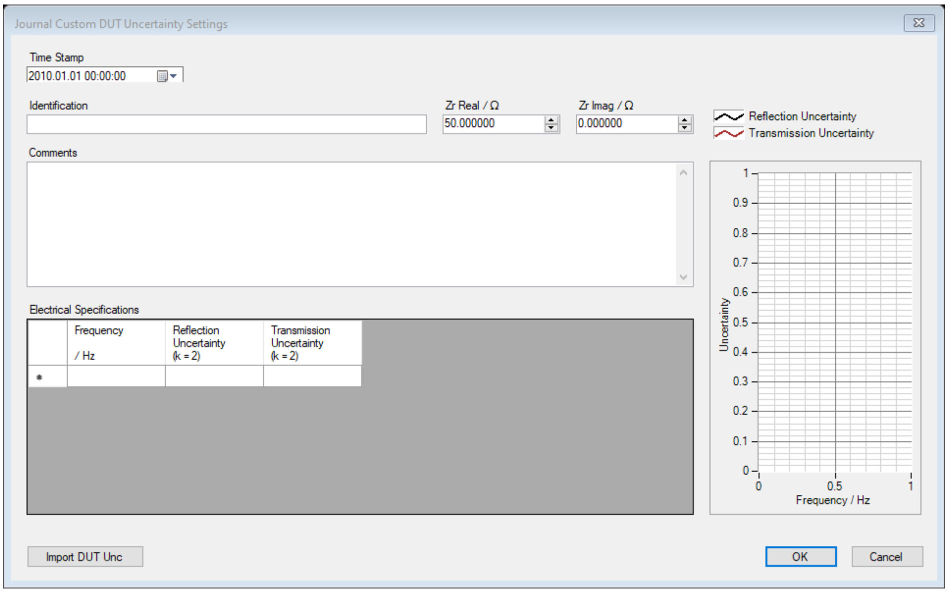

Figure 43: Measurement Journal / Custom DUT Uncertainty Settings

are available:

Time Stamp specifies the time stamp of the journal item.

Identification field can contain an identification string.

Zr Real / Ω specifies the real part of the reference impedance in Ohm.

Zr Imag / Ω specifies the imaginary part of the reference impedance in Ohm.

Comments field can contain user comments.

Electrical Specifications is a table with the following columns:

- Frequency in Hz
- Reflection Uncertainty with $k = 2$
- Transmission Uncertainty with $k = 2$

Import DUT Unc imports a DUT uncertainty from the database.

5.10 Measurement

The Measurement dialog is designed to collect measurement data from the VNA, see figure 44. The following user controls are available:

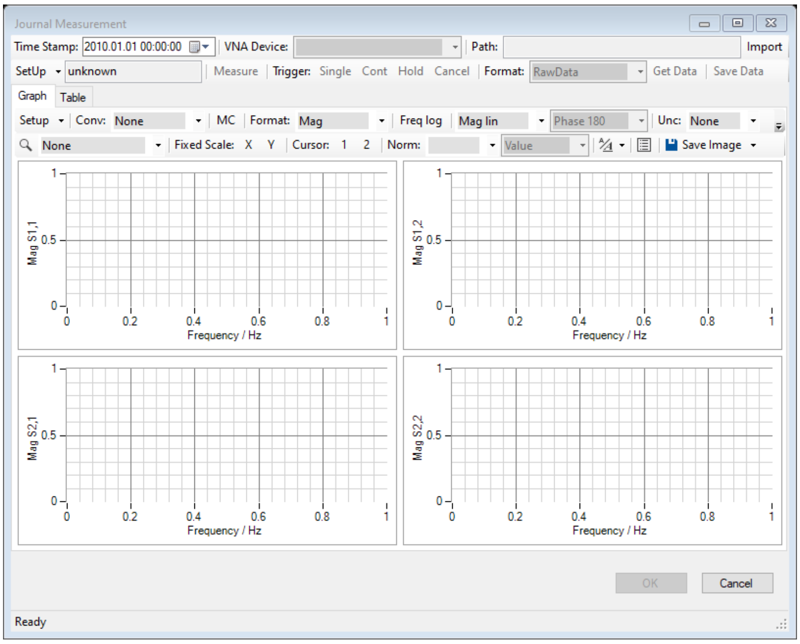

Figure 44: Measurement Journal / Measurement

Time Stamp specifies the time stamp of the journal item.

VNA Device specifies the VNA device.

Path field contains the path of the measurement data.

Import imports an existing file instead of making a new VNA measurement. Only available if VNA connection is closed.

Mode selects a setup mode for the VNA, e.g. S1,1.

SetUp sets up the VNA to the selected mode.

Measure performs a single sweep on the VNA, wait until the sweep is complete and reads out the data.

Trigger Single performs a single sweep on the VNA and waits until the sweep is complete.

Trigger Cont sets the trigger of the VNA to continuous mode.

Trigger Hold sets the trigger of the VNA to hold mode.

Trigger Cancel cancels the current sweep.

Format sets the format to Raw Data or Error Corrected Data (default: Raw Data).

Get Data reads out the data from the VNA.

Save Data saves the data to an S-parameter file (*.sdatb).

5.11 Experiment

The Experiment dialog is designed to describe an experiment, see figure 45. Experiments are necessary for DUTs with bad repeatability. The journal items of the type experiment will cause VNA Tools to determine the repeatability of the measurement from repeated measurements. If no journal items of the type experiment are used, the repeatability uncertainties from the database will be used. The following user controls are available:

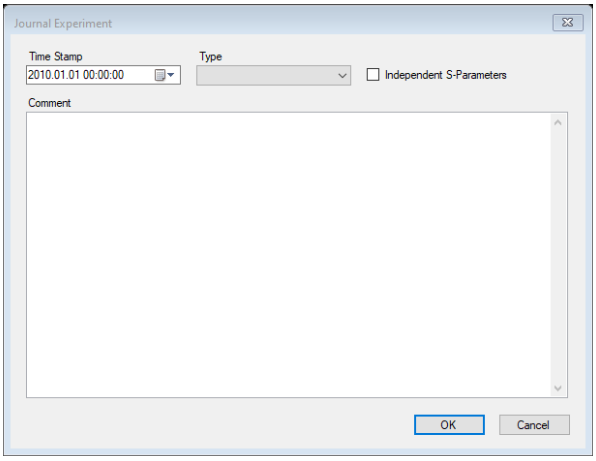

Figure 45: Measurement Journal / Experiment

Time Stamp specifies the time stamp of the journal item.

Type sets the type of the experiment to Statistical or Systematic (default: Statistical). Statistical assumes a mono modal distribution for the resulting uncertainties. Systematic assumes a multi modal distribution.

Independent S-Parameters ignores correlation between different S-Parameters.

Comments field can contain user comments.

5.12 Measurement Series

The dialog, called Measurement Series, is designed to collect a series of measurements, see figure 46. The following user controls are available:

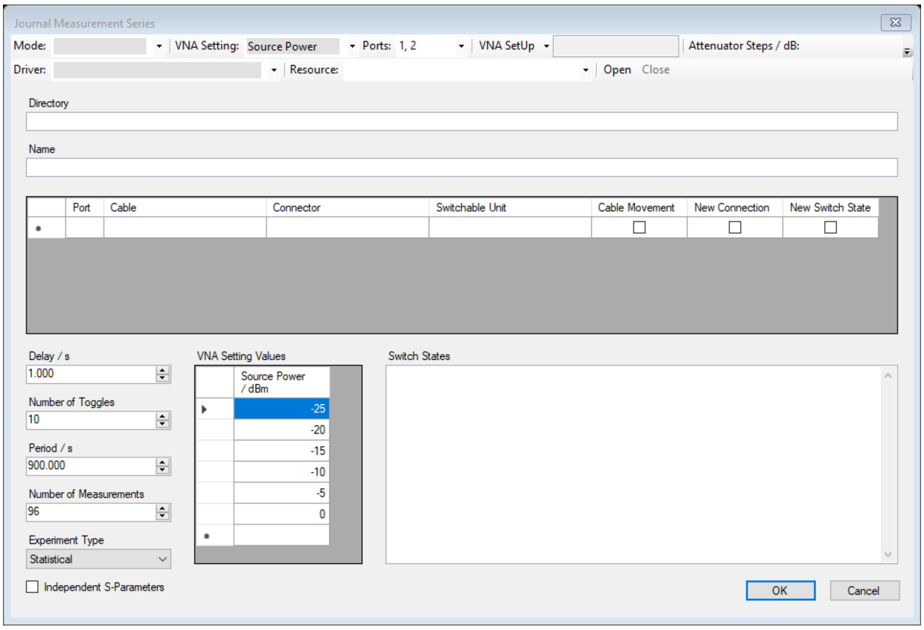

Figure 46: Measurement Journal / Measurement Series

Mode sets the mode of the measurement series. The following modes are available:

- DUT
- DUT Experiment
- Sliding Load
- Step Attenuator
- Switch States
- ECU
- Drift
- ECU Drift
- VNA Settings

VNA Settings sets the VNA setting which will be changed during the measurement series. The following VNA settings are available:

- Dwell Time in s

- IF Average Factor
- IF Bandwidth in Hz
- Source Power in dBm
- Source Slope in dB/GHz

Ports specifies the ports used for the source settings. Multiple ports are comma separated, e.g. '1, 2'.

VNA SetUp sets up the VNA to the selected mode.

Attenuator Steps / dB specifies the attenuator steps in dB for a measurement series of the type step attenuator. Multiple steps are comma separated, e.g. '10, 20, 40, 40'.

Only Single Sections measures only the single sections and not all combinations.

ECU Path specifies the path of the ECU where all states will be measured. Multiple paths are comma separated, e.g. 'A, B, AB'. Where 'A' and 'B' are reflection paths and 'AB' is a transmission path. For some manufacturers 'A' is port 1 and 'B' is port 2.

Driver sets the driver for the communication with the Switch or ECU device.

Resource sets the VISA resource name of the Switch or ECU device.

Open opens the VISA connection to the Switch or ECU device.

Close closes the VISA connection to the Switch or ECU device.

Directory sets the parent directory that will contain the directory of the measurement series.

Name specifies a name for the measurement series. A directory will be created with this name.

Cable, Connector and Switchable Unit Table specifies the used test port cable, connector and switchable unit for each port.

Cable movement adds one or multiple entries for cable movements at the selected ports in the measurement journal before the measurement series.

New connection adds one or multiple entries for new connections at the selected ports in the measurement journal before the measurement series.

New switch state adds one or multiple entries for new switch states at the selected ports in the measurement journal before the measurement series.

Delay / s sets the delay between switching states and start of the measurements in s (default: 1 s).

Number of Toggles sets the number of switching cycles that are performed on the step attenuator before the measurement series is started (default: 10).

Period / s sets the period between measurements for drift evaluation in s (default: 900 s).

Number of Measurements sets the number of measurements for drift evaluations (default: 96).

Experiment Type sets the type of the experiment to Statistical or Systematic (default: Statistical). Statistical assumes a mono modal distribution for the resulting uncertainties. Systematic assumes a multi modal distribution.

Independent S-Parameters ignores correlation between different S-Parameters.

Switch States sets the list of switch states which will be measured. Each line in this text box specifies one state. '0' is off, '1' is on and 'x' is don't change.

VNA Setting Values specifies the list of VNA setting values at which the DUT will be measured.

5.13 Measurement Power Sensor

The dialog, called Measurement Power Sensor, is designed to collect a measurement of a power sensor, see figure 47. The following user controls are available:

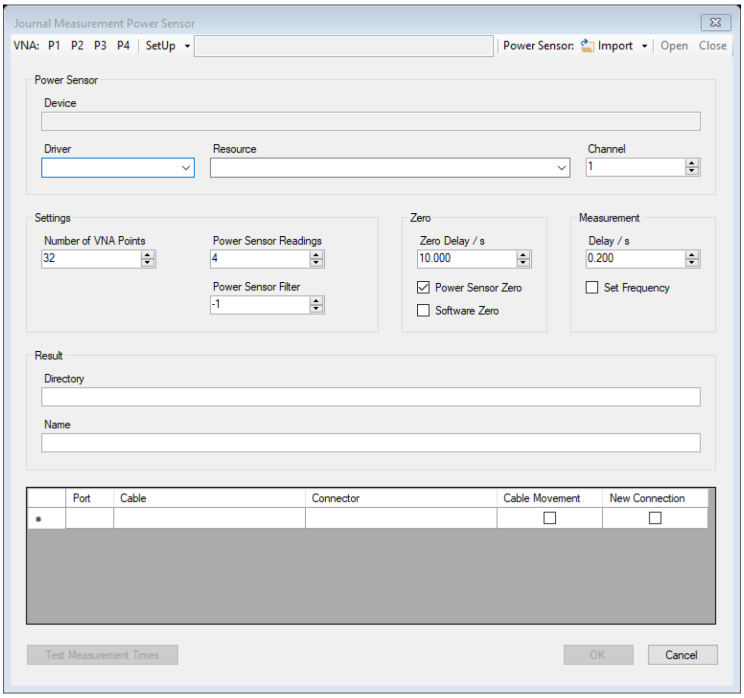

Figure 47: Measurement Journal / Measurement Power Sensor

P1 sets up the VNA to measure S1,1 and the reference receiver of port 1.

P2 sets up the VNA to measure S2,2 and the reference receiver of port 2.

P3 sets up the VNA to measure S3,3 and the reference receiver of port 3.

P4 sets up the VNA to measure S4,4 and the reference receiver of port 4.

SetUp sets up the VNA to the selected mode.

Import imports a power sensor from the database.

Open opens the VISA connection to the power sensor.

Close closes the VISA connection to the power sensor.

Device shows the imported power sensor.

Driver sets the driver for the communication with the power sensor.

Resource sets the VISA resource name of the power sensor.

Channel sets the channel (default: 1) of the power meter to which the power sensor is connected to.

Number of VNA Points sets the number of VNA points at each frequency (default: 32). This number will be automatically increased if the time span of the power measurement is longer than the VNA sweep time.

Power Sensor Readings sets the number of power readings at each frequency (default: 4).

Power Sensor Filter sets the filter of the power sensor (default: -1 Auto Once). The following values are allowed:

- **-2: Auto** detects the filter length automatically for each reading. This mode is not recommended due to changing power measurement time.
- **-1: Auto Once** detects the filter length automatically based on the first reading for each frequency.
- **Positive Values** specifies the filter length.

Zero Delay / s sets the delay between turning off the VNA source and zeroing the power sensor in s (default: 10 s).

Zero zeros the power sensor before measuring the first frequency (default: true).

Software Zero performs a zero measurement before measuring the first frequency (default: false). The zero measurement is subtracted from all following measurements.

Delay / s sets the delay between starting the VNA sweep at each frequency and starting the power measurements in s (default: 0.2 s).

Set Frequency sets the frequency to the power sensor (default: false). If not selected the default frequency of the power sensor, e.g.: 50 MHz, is used for all frequencies.

Directory sets the parent directory that will contain the directory of the measurements of a power sensor.

Name specifies a name for the measurement of a power sensor. A directory will be created with this name.

Cable and Connector Table specifies the used test port cable and connector for each port.

Test Measurement Times measures the VNA and the power sensor measurement times. The VNA measurement time should be longer than the power sensor measurement time but not more than 10 percent.

5.14 Spectrum Analyzer Settings

The dialog, called Spectrum Analyzer Settings, is designed to set up a spectrum analyzer, see figure 48. The following user controls are available:

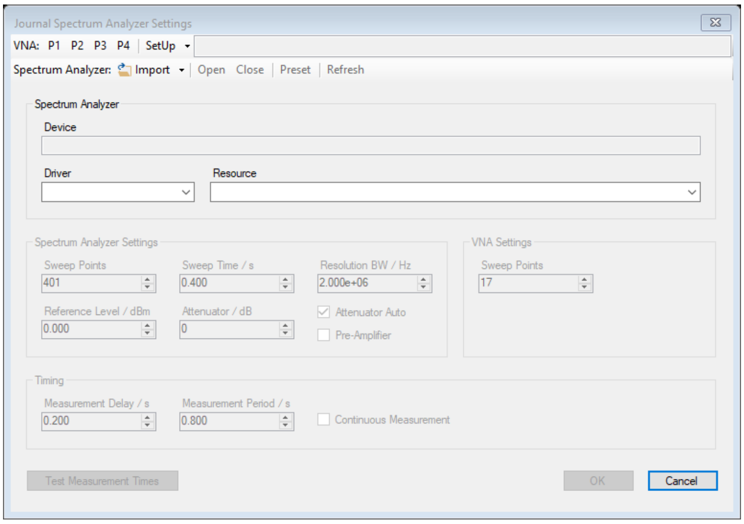

Figure 48: Measurement Journal / Spectrum Analyzer Settings

P1 sets up the VNA to measure S1,1 and the reference receiver of port 1.

P2 sets up the VNA to measure S2,2 and the reference receiver of port 2.

P3 sets up the VNA to measure S3,3 and the reference receiver of port 3.

P4 sets up the VNA to measure S4,4 and the reference receiver of port 4.

SetUp sets up the VNA to the selected mode.

Import imports a spectrum analyzer from the database.

Open opens the VISA connection to the spectrum analyzer.

Close closes the VISA connection to the spectrum analyzer.

Device shows the imported spectrum analyzer.

Driver sets the driver for the communication with the spectrum analyzer.

Resource sets the VISA resource name of the spectrum analyzer.

SA Sweep Points sets the number of SA sweep points at each frequency (default: 401).

SA Sweep Time / s sets the sweep time of the SA in s (default: 0.4 s).

SA Resolution BW / Hz sets the resolution bandwidth of the SA in Hz (default: 2 MHz).

SA Reference Level / dBm sets the reference level of the SA in dBm (default: 0 dBm).

SA Attenuator / dB sets the attenuator of the SA in dB (default: 0 dB).

SA Attenuator Auto turns the automatic selection of the attenuator of the SA off or on (default: on).

SA Pre-Amplifier turns the pre-amplifier of the SA off or on (default: off).

VNA Sweep Points sets the number of VNA sweep points at each frequency (default: 17). This number will be automatically increased if the SA sweep time is longer than the VNA sweep time.

Measurement Delay / s sets the delay between starting the VNA sweep at each frequency and starting the SA sweep in s (default: 0.2 s).

Measurement Period / s sets the measurement period in s (default: 0.8 s).

Continuous Measurements turns continuous measurement of the SA off or on (default: off).

Test Measurement Times measures the VNA and the SA measurement times. The VNA measurement time should be longer than the SA measurement time but not more than 10 percent.

5.15 Measurement Spectrum Analyzer

The dialog, called Measurement Spectrum Analyzer, is designed to collect a measurement of a spectrum analyzer, see figure 49. The following user controls are available:

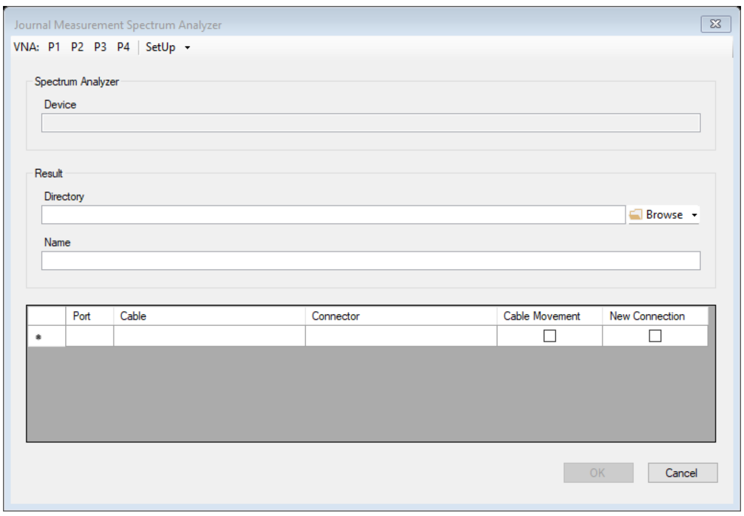

Figure 49: Measurement Journal / Measurement Spectrum Analyzer

P1 sets up the VNA to measure S1,1 and the reference receiver of port 1.

P2 sets up the VNA to measure S2,2 and the reference receiver of port 2.

P3 sets up the VNA to measure S3,3 and the reference receiver of port 3.

P4 sets up the VNA to measure S4,4 and the reference receiver of port 4.

SetUp sets up the VNA to the selected mode.

Device shows the spectrum analyzer.

Directory sets the parent directory that will contain the directory of the measurements of a spectrum analyzer.

Name specifies a name for the measurement of a spectrum analyzer. A directory will be created with this name.

Cable and Connector Table specifies the used test port cable and connector for each port.

5.16 User Comment

The dialog, called User Comment, is designed to add user comments to the journal, see figure 50. The following user controls are available:

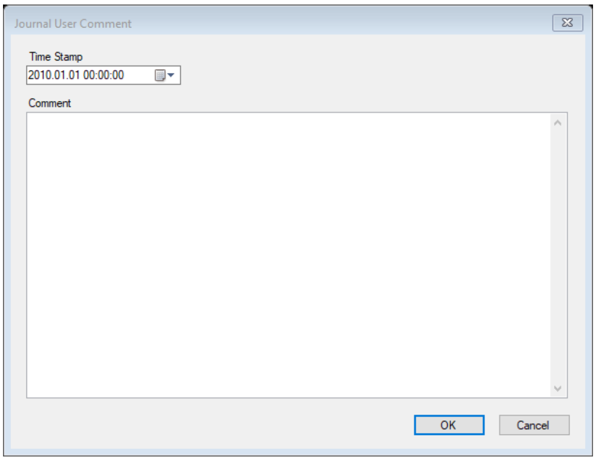

Figure 50: Measurement Journal / User Comment

Time Stamp specifies the time stamp of the journal item.

Comments field can contain user comments.

6 Calibration Config

The tabular page, called Calibration Config, is designed to configure a VNA calibration. The result will be the switch and error terms of the VNA. For more details see appendix E. There are two models of the VNA:

Generic Model stores the switch terms in a N-port and the error terms are stored in a $2N$-port for a N-port VNA. It supports the following calibration types: One Port, GSOLT, QSOLT, Unknown Thru, TRL (only 2-port), Juroshek, LHKM (TRL, LRL, TRM, LRM), Frequency Conversion Scalar Mixer, Frequency Conversion Unknown Mixer and Optimization. For more details see appendix E.1.

Switched Model stores the error terms in a $2N$-port for each switch position for a N-port VNA. It supports the following calibration types: SOLT, Reflection Normalization, Transmission Normalization and One Path Two Ports. For more details see appendix E.2.

On the tabular page, called Calibration Config, the following user controls are available, see figure 51:

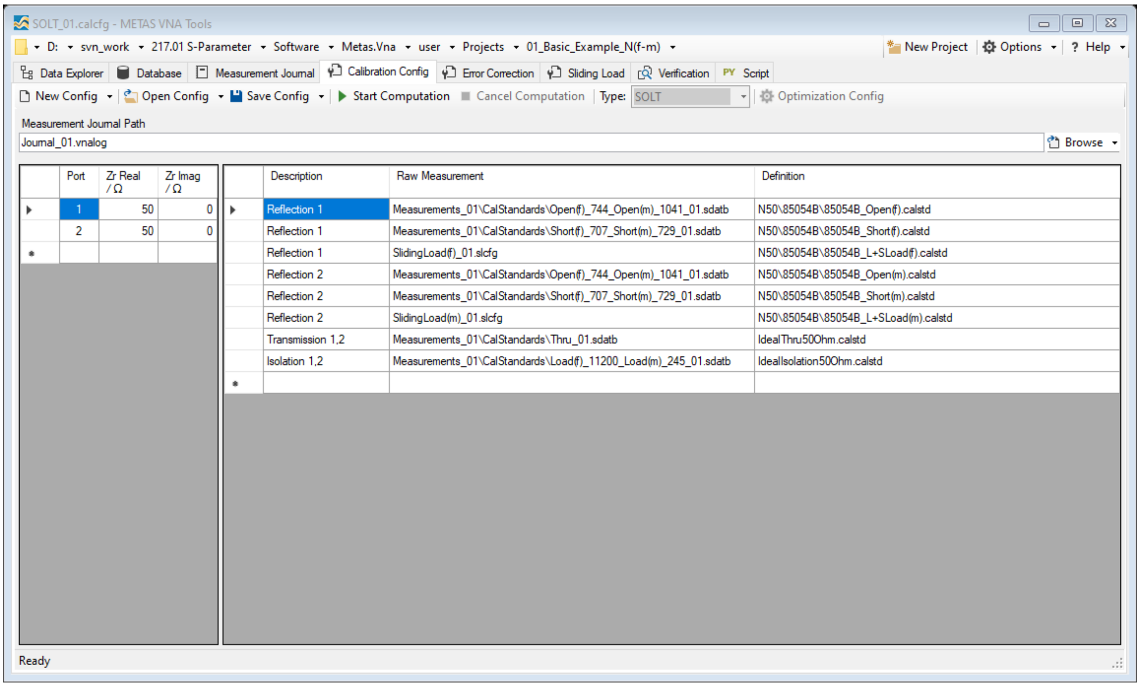

Figure 51: Calibration Config

New Config creates a new calibration configuration (shortcut: Ctrl + N), see section 6.1.

New Config from Template loads a configuration template.

Open Config loads an existing configuration from a file (*.calcfg), (shortcut: Ctrl + O).

Save Config saves the configuration to a file (*.calcfg), (shortcut: Ctrl + S).

Start Computation computes the VNA calibration and saves the VNA calibration to a file (*.calb), (shortcut: Ctrl + R).

Cancel Computation cancels the computation (shortcut: Ctrl + T).

Optimization Config edits the optimization parameters, see section 6.2.

Measurement Journal Path sets the path (*.vnalog) for the measurement journal. All measurements used for the calibration have to be in the measurement journal.

Port specifies the port assignment for each test port.

Zr / Ω specifies the complex reference impedance for each test port.

Description specifies the type of calibration standard and the ports which were measured.

Additionally one can specify the weight of the standard in an optimization calibration. The default setting is that all standards have equal weight. The weighting can be switched to covariance weighting in the optimization parameters dialog. Mathematical details about weighting schemes are given in VNA Tools - Math Reference.

Some calibration standards are assumed to be the same or they are measured several times. In such cases one can couple variables which describe the standard. E.g.: In an LRL calibration with 7 mm connectors the flush short is the same for port 1 and 2.

Raw Measurement specifies the path (*.sdatb, *.vdatb) where the data of the measured standard is. Only the configuration (*.slcfg) is given for the sliding load. A measurement (*.sdatb, *.vdatb), a generic calibration (*.calb) or a non-leaky switched calibration (*.calb) can be given for the switch terms. It is possible to specify an N-port file for 1-port standards. In such a case the number in the description field defines which part of the data is used. E.g. only S1,1 of a 2-port file is used in a line where the description field is set to Reflection 1.

Definition specifies the path (*.calstd) which contains the definition of the standard. Leave this cell empty for a switch term row.

6.1 New Calibration Config

The dialog, called New Calibration Config, is designed to create a new calibration configuration, see figure 52. The following user controls are available:

Calibration Type specifies the calibration type, e.g.: SOLT.

Ports specifies the used ports as a comma separated list.

Zr / Ω specifies the complex reference impedance.

Isolation Calibration enables the isolation calibration. This adds additional isolation standards to the calibration configuration.

Power Calibration enables the power calibration. This adds additional power standards to the calibration configuration. For measuring a power standard, see section 5.13.

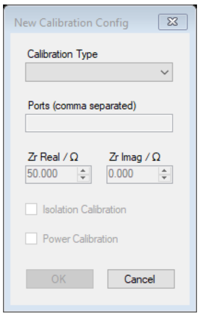

Figure 52: New Calibration Config

6.2 Optimization Parameters

The dialog, called Optimization Calibration Config, is designed to configure the optimization parameters, see figure 53. The following user controls are available:

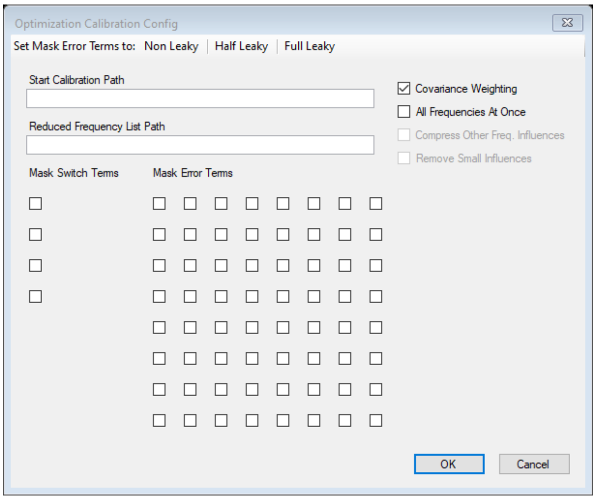

Figure 53: Optimization Calibration Config

Set Mask Error Terms sets the mask of the error terms for a non-, half- or full-leaky model of the VNA. Typically this is set to non-leaky.

Start Calibration Path specifies the start values used for the optimization (*.calb).

Reduced Frequency List Path specifies a frequency list (*.fl). The optimizer uses the listed frequency points. If no frequency list is specified, all available frequency points are used.

Covariance Weighting uses covariance weighting for the objective function. If not checked, all standards are equally weighted. If supplied, the user specified weights are applied.

All Frequencies At Once optimizes all frequencies at once. This is needed when calibration standards are used with unknown parameters which are constant over frequency. Example given: Primary airlines, primary offset shorts and primary flush shorts. If not checked, each frequency will be optimized individually.

Compress Other Freq. Influences compresses small uncertainties of other frequency influences after optimization ($< 10^{-6}u$) where u is the standard uncertainty.

Remove Small Influences removes small uncertainty influences after optimization ($< 10^{-7}u$) where u is the standard uncertainty.

Mask Switch Terms selects the switch terms which will be optimized.

Mask Error Terms selects the error terms which will be optimized. This mask represents a $2N \times 2N$ S-parameter matrix for a VNA with N ports. In the upper left part of the matrix are the directivity and isolation terms. The match terms are in the lower right of the diagonal. The other check boxes represent tracking terms. For more details see appendix E.1.

7 Error Correction

The tabular page, called Error Correction, is designed to configure the error correction of the raw measurement data, see figure 54. The following user controls are available:

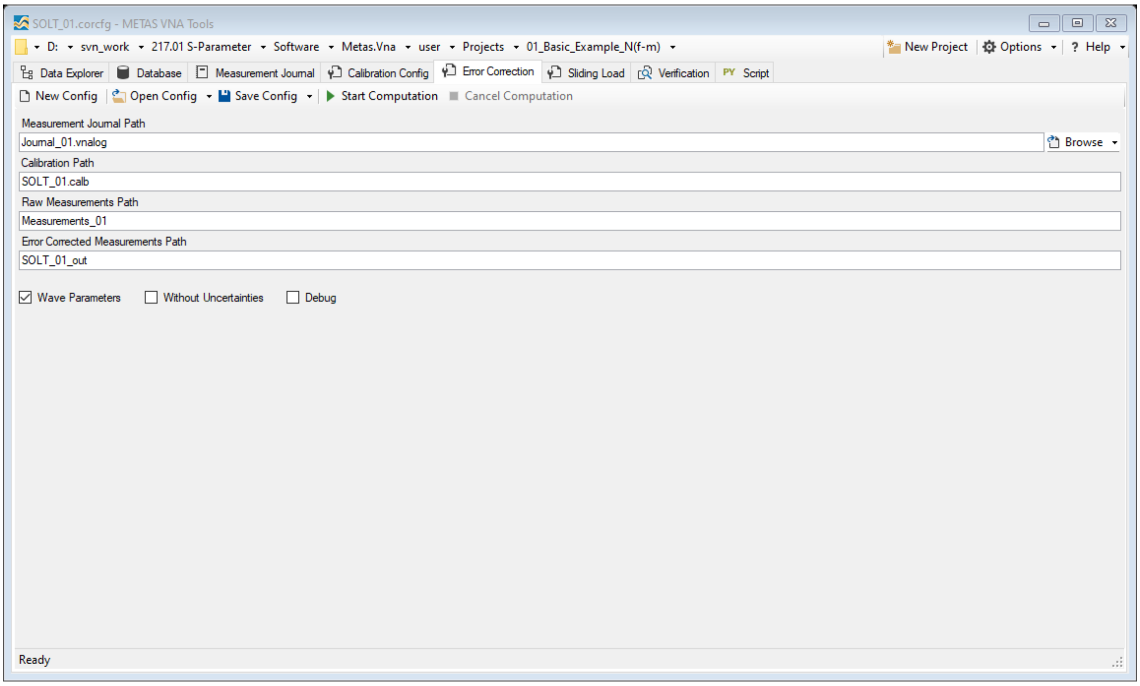

Figure 54: Error Correction

New creates a new configuration for error correction (shortcut: Ctrl + N).

Open Config loads an existing configuration from a file (*.corcfg), (shortcut: Ctrl + O).

Save Config saves the configuration to a file (*.corcfg), (shortcut: Ctrl + S).

Start Computation computes the error correction (shortcut: Ctrl + R).

Cancel Computation cancels the computation (shortcut: Ctrl + T).

Measurement Journal Path sets the path (*.vnalog) for the measurement journal. All raw measurements have to be in the measurement journal.

Calibration Path sets the calibration path (*.calb).

Raw Measurement Path sets the directory which contains the raw data.

Error Corrected Measurement Path specifies the path where the error-corrected data will be stored. All files from the Raw Measurement Path and all subdirectories will be error-corrected and stored in this directory.

Wave Parameters error corrects wave parameter data if available.

Without Uncertainties disables uncertainty propagation.

Debug stores $\mathbf{R}$ noise and linearity, $\mathbf{V}$ drift of switch terms, $\mathbf{D}$ drift of error terms and $\mathbf{C}$ cable stability, connector repeatability and DUT uncertainty for each measurement.

8 Sliding Load

The tabular page, called Sliding Load, is designed to configure and compute the circle fit of a sliding load. It merges the circle fit with the measurement of a low-band load at the specified frequency point, see figure 55. The following user controls are available:

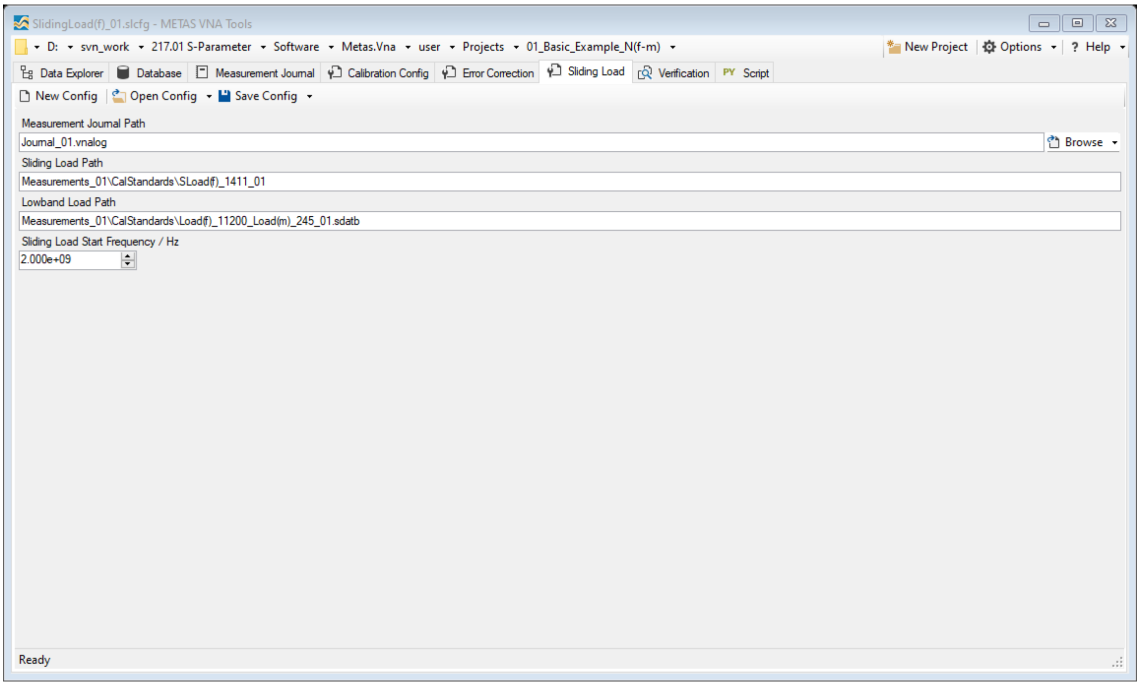

Figure 55: Sliding Load

New creates a new configuration for a sliding load (shortcut: Ctrl + N).

Open Config loads an existing configuration from a file (*.slcfg), (shortcut: Ctrl + O).

Save Config saves the configuration to a file (*.slcfg), (shortcut: Ctrl + S).

Measurement Journal Path sets the path (*.vnalog) for the measurement journal. The files of the sliding load and the low-band load have to be in the measurement journal.

Sliding Load Path sets the directory where the raw measurements of the sliding load are.

Lowband Load Path sets the path (*.sdatb, *.vdatb) where the file of the raw measurement of the low-band load is.

Sliding Load Start Frequency / Hz sets the start frequency of the sliding load in Hz. Below this frequency the measurement data of the low band load is used.

9 Verification

The tabular page, called Verification, is designed to configure and verify error corrected measurements against some reference data, see figure 56. The following user controls are avail-

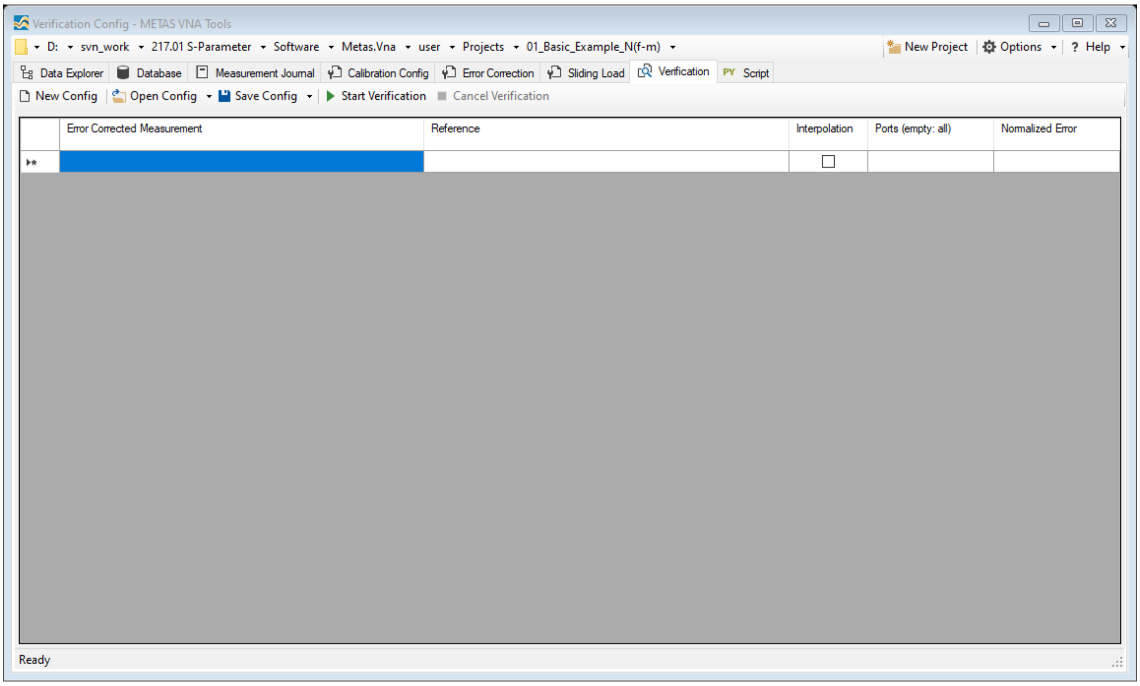

Figure 56: Verification

able:

New Config creates a new configuration for verification (shortcut: Ctrl + N).

Open Config loads an existing configuration from a file (*.vercfg), (shortcut: Ctrl + O).

Save Config saves the configuration to a file (*.vercfg), (shortcut: Ctrl + S).

Start Verification computes the normalized errors for each verification standard (shortcut: Ctrl + R).

Cancel Verification cancels the computation (shortcut: Ctrl + T).

Error Corrected Measurement specifies the path (*.sdatb, *.vdatb) where the error corrected data of the verification standard is.

Reference specifies the path (*.calstd) which contains the reference data or definition of the verification standard.

Interpolation specifies if a databased verification standard is interpolated to the frequency list of the measurement or not. If interpolation is not selected (default), only the common frequency points are compared.

Ports specifies which ports of the verification standards are used for comparison (empty: all).

Normalized Error shows the computed normalized error for each verification standard.

10 Script

The tabular page, called Script, provides a built-in Iron Python script engine, see figure 57. The following user controls are available:

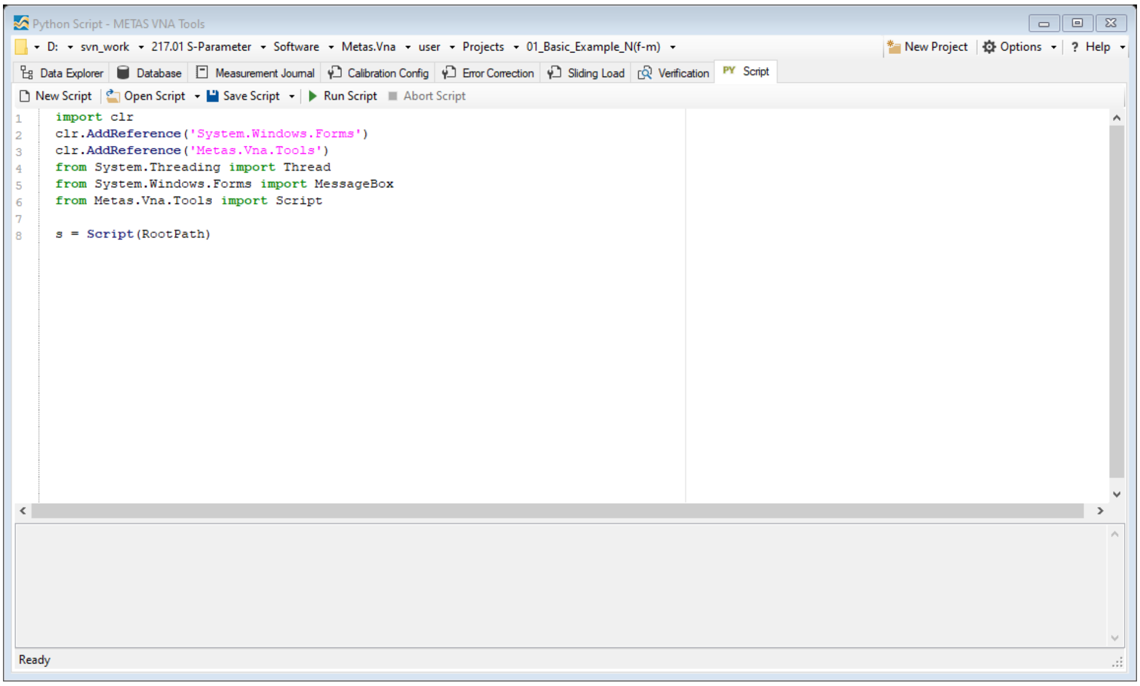

Figure 57: Script

New Script creates a new script (shortcut: Ctrl + N).

Open Script loads an existing script from a file (*.py), (shortcut: Ctrl + O).

Save Script saves the script to a file (*.py), (shortcut: Ctrl + S).

Run Script executes the script (shortcut: Ctrl + R).

Abort Script aborts the execution of the script (shortcut: Ctrl + T).

Input field shows the script.

Output field shows the output of the script.

A Calibration Standard Model Fit

The dialog, called Calibration Standard Model Fit, computes the parameters of a calibration standard for an Agilent, Anritsu and Rohde Schwarz model, see figure 58. The following user

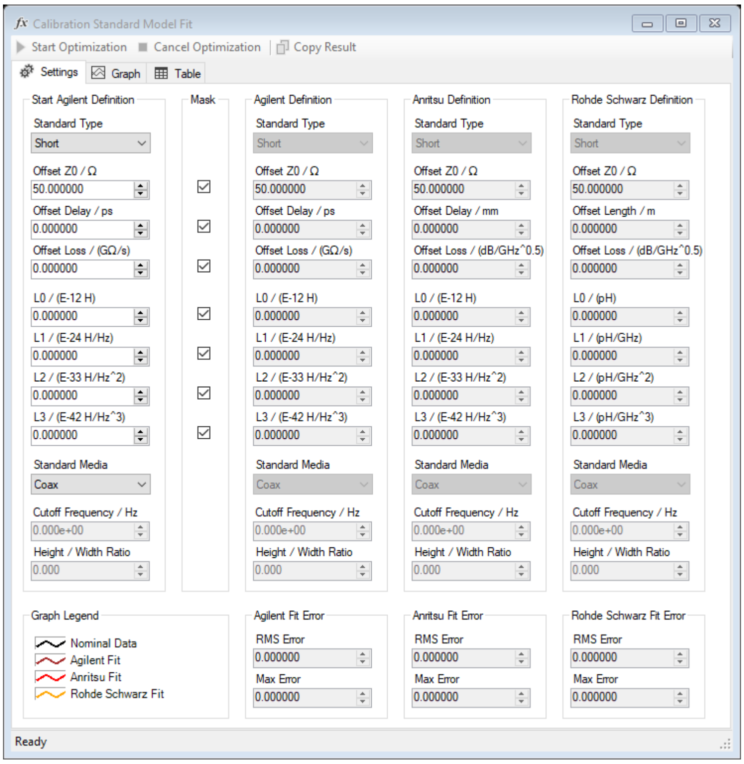

Figure 58: Calibration Standard Model Fit

controls are available:

Start Optimization starts optimization of the selected parameters.

Cancel Optimization aborts optimization.

Copy Result copies the result to the clipboard.

Start Agilent Definition describes the start values for the optimization.

Mask selects optimization parameters.

Agilent Definition shows the result for the Agilent model.

Agilent Fit Error shows the fit error for the Agilent model.

Anritsu Definition shows the result for the Anritsu model.

Anritsu Fit Error shows the fit error for the Anritsu model.

Rohde Schwarz Definition shows the result for the Rohde Schwarz model.

Rohde Schwarz Fit Error shows the fit error for the Rohde Schwarz model.

B File Types

Table 5 shows the supported file types. S-Parameter Data files can only contain S-parameter data. In contrast VNA Data files can contain receiver values and ratios of receiver values.

Table 5: File types

Description	Extension
S-Parameter Data Binary	(.sdatb)
S-Parameter Data Xml	(.sdatx)
S-Parameter Data Covariance Text	(.sdatcv)
S-Parameter Data MMS4 DSD Text[1]	(.dsd)
S-Parameter Data Touchstone	(.s*p)
S-Parameter Data Touchstone V2.0	(.ts)
VNA Data Binary	(.vdatb)
VNA Data Xml	(.vdatx)
VNA Data CITI	(.cti;.citi)
S-Parameter Data Collection Binary	(.scolb)
S-Parameter Data Collection Covariance Text	(.scolcv)
VNA Data Collection Binary	(.vcolb)
VNA Data Collection Covariance Text	(.vcolcv)
Database VNA Device	(.vnadev)
Database Cable	(.cable)
Database Connector	(.conn)
Database DUT Uncertainty	(.dutunc)
Database Calibration Standard	(.calstd)
Database CMC Entry	(.cmc)
Database Logger Device	(.logdev)
Measurement Journal	(.vnalog)
Calibration Config	(.calcfg)
Calibration Data Binary	(.calb)
Calibration Data Xml	(.calx)
Error Correction Config	(.corcfg)
Sliding Load Config	(.slcfg)
Python Script	(.py)
Frequency List	(.fl)
ZIP with embedded data files	(.zip)
PDF with embedded data files	(.pdf)

[1] readonly

C Naming Convention

The here described naming convention is meant as a help for the user. It is not required by VNA Tools. Table 6 shows some examples for the naming convention.

Table 6: Naming convention examples

Description	Name
Coaxial DUT	'[DUT][Gender]_[SN]'
Coaxial DUT	'[DUT]_[Conn 1][Gender 1]_[Conn 2][Gender 2]_[SN]'
Waveguide DUT	'[DUT]_[SN]_[Orientation]'
Waveguide DUT	'[DUT]_[Conn]_[SN]_[Orientation]'

Table 7 shows some examples for names of calibration standards and devices under test. Table 8 shows the naming convention for the different connector types. Table 9 shows the naming convention for the gender of connectors. Table 10 shows the naming convention for the orientation of waveguides. Figure 59 shows a typical project example.

Table 7: DUT types

Description	Name
Open	'Open'
Short (n)	'Short$[n]$'
Flush Short	'FShort'
Load	'Load'
Sliding Load	'SLoad'
Mismatch	'MMatch'
Power Sensor	'PSensor'
Thru	'Thru'
Line l mm	'Line$[l]$mm'
Shim	'Shim'
Adapter	'Ada'
Matching Pad	'MPad'
Match Thru	'MThru'
Mismatch Thru	'MmThru'
Attenuator a dB	'Att$[a]$dB'
Step Attenuator a dB, selected state: s, x dB	'StepAtt$[a]$dB_$[s]$_$[x]$dB'
Splitter	'Splitter'
Coupler	'Coupler'

Table 8: Connector types

Description	Name
1.0 mm Connector	'1.0mm'
1.85 mm Connector	'1.85mm'
2.4 mm Connector	'2.4mm'
2.92 mm Connector	'2.92mm'
3.5 mm Connector	'3.5mm'
7 mm Connector	'7mm'
BNC 50 Ω Connector	'BNC50'
BNC 75 Ω Connector	'BNC75'
Type N 50 Ω Connector	'N50'
Type N 75 Ω Connector	'N75'
Waveguide WR10 Connector	'WR10'

Table 9: Gender of connectors

Description	Name
1-Port DUT female	'(f)'
1-Port DUT male	'(m)'
2-Port DUT female male	'(f-m)'
2-Port DUT male female	'(m-f)'
N-Port DUT female male male . . .	'(f-m-m-. . .)'
N-Port DUT genderless	''

Table 10: Orientation of waveguides

Description	Name
1-Port DUT label up	'U'
1-Port DUT label down	'D'
1-Port DUT label left	'L'
1-Port DUT label right	'R'
2-Port DUT label up on test port side 1	'U1'
2-Port DUT label down on test port side 1	'D1'
2-Port DUT label left on test port side 1	'L1'
2-Port DUT label right on test port side 1	'R1'
2-Port DUT label up on test port side 2	'U2'
2-Port DUT label down on test port side 2	'D2'
2-Port DUT label left on test port side 2	'L2'
2-Port DUT label right on test port side 2	'R2'

```
Example_2.4mm(f-m)_01 .................................... project directory
├── Measurements_01 ............................................ raw data
│   ├── CalStandards
│   │   ├── SLoad(f)_1567_01
│   │   │   ├── SLoad(f)_1567_01_N1.sdatb
│   │   │   ├── SLoad(f)_1567_01_N2.sdatb
│   │   │   └── ...
│   │   ├── SLoad(m)_1763_01
│   │   │   ├── SLoad(m)_1763_01_N1.sdatb
│   │   │   ├── SLoad(m)_1763_01_N2.sdatb
│   │   │   └── ...
│   │   ├── Load(f)_451_Load(m)_3218_01.sdatb
│   │   ├── Open(f)_975_Open(m)_999_01.sdatb
│   │   ├── Short(f)_747_Short(m)_2887_01.sdatb
│   │   ├── SwitchTerms_01.vdatb
│   │   └── Thru_01.sdatb
│   └── DUTs
│       ├── Ada_2.4mm(f)_1.85mm(m)_123_01.sdatb
│       ├── Att20dB(f-m)_808_01.sdatb
│       └── ...
├── SOLT_01_out ........................................ error correted data
│   ├── CalStandards
│   └── DUTs
│       ├── Ada_2.4mm(f)_1.85mm(m)_123_01.sdatb
│       ├── Att20dB(f-m)_808_01.sdatb
│       └── ...
├── UThru_01_out ....................................... error correted data
│   ├── CalStandards
│   └── DUTs
│       ├── Ada_2.4mm(f)_1.85mm(m)_123_01.sdatb
│       ├── Att20dB(f-m)_808_01.sdatb
│       └── ...
├── Journal_01.vnalog ................................. measurement journal
├── SlidingLoad_01.slcfg ................................ sliding load config
├── SlidingLoad_02.slcfg ................................ sliding load config
├── SOLT_01.calb ............................................ calibration data
├── SOLT_01.calcfg ........................................ calibration config
├── SOLT_01.corcfg .................................. error correction config
├── UThru_01.calb ........................................... calibration data
├── UThru_01.calcfg ....................................... calibration config
└── UThru_01.corcfg ................................. error correction config
```

Figure 59: Tree view of a VNA Tools project example

D Drivers

The following VNA's are supported by METAS VNA Tools:

- Agilent 8719D/ES, 8720D/ES, 8722D/ES (Firmware: 8722ES 07.74)
- Agilent 8753B/C/D/E/ES (Firmware: 8753B 03.00, 8753D 06.14)
- Agilent ENA Series (Firmware: E5061B A.02.06, E5071C A.09.60)[1]
- Agilent FieldFox Series (Firmware: N99xx A.10.34)
- Agilent PNA Series (Firmware: E836x & N52xx A.09.40, E5080B A.11.00, M937x & M948x & M980x & P50xx A.13.90.06)[1]
- Anritsu ShockLine (Firmware: MS46524A V2018.2.1, V2.2.17/V2.2.05)[1]
- Anritsu VectorStar (Firmware: MS4640A 1.7.5, MS4640B 2.1.0)[1]
- Hewlett Packard 8510C (Firmware: 07.14 Aug 26 1998)
- Hewlett Packard 8751A (Firmware: 5.00 Mar 7 1993)
- Rohde & Schwarz ZNA, ZNB, ZNC, ZND, ZNBT, ZNL, ZNLE (Firmware: ZNA 2.15, ZNB 1.94, ZNLE 1.31)[1]
- Rohde & Schwarz ZVA, ZVB, ZVT (Firmware: 3.20)[1]
- Rohde & Schwarz ZVC, ZVK, ZVM, ZVR (Firmware: 3.55)
- Copper Mountain Technologies PLANAR 804/1 (SW: 16.1.0, HW: 01)[2]

The following switch drivers are supported by METAS VNA Tools:

- Agilent 11713A/C

The following electronic calibration units are supported:

- Agilent ECal connected to an Agilent ENA Series VNA (Firmware: E5061B A.02.06).
- Agilent ECal connected to an Agilent PNA Series VNA.
- Anritsu Autocal connected to an Anristu ShockLine VNA.
- Anritsu Autocal connected to an Anristu VectorStar VNA.
- Rohde & Schwarz Calibration Unit connected to a Rohde & Schwarz VNA.

The following power meters are supported:

- Keysight EPM Series
- Rohde & Schwarz NRP, NRP2, NRX
- Rohde & Schwarz NRVS, NRVD
- Virginia Diodes Erickson PM5

[1] two-port and multiport
[2] driver developed by Copper Mountain Technologies

D.1 IVI.VISA

METAS VNA Tools requires one of the following IVI.VISA implementations.

D.1.1 National Instruments VISA

National Instruments VISA 19.0 is the minimum required version by METAS VNA Tools. Make sure that NI-VISA.NET Development Support and NI-VISA.NET Runtime items are selected in the installation process, see figure 60.

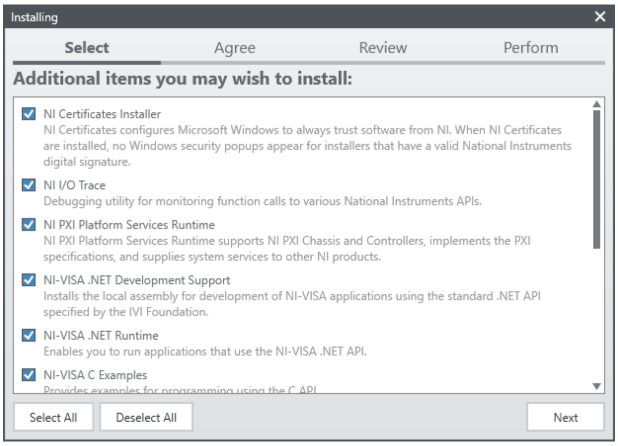

Figure 60: National Instruments VISA 19.0

D.1.2 Keysight IO Libraries Suite

Keysight IO Libraries Suite 2023 is the minimum required version by METAS VNA Tools. Make sure that IVI .NET Shared Components and VISA .NET Shared Components are selected in the installation process, see figure 61.

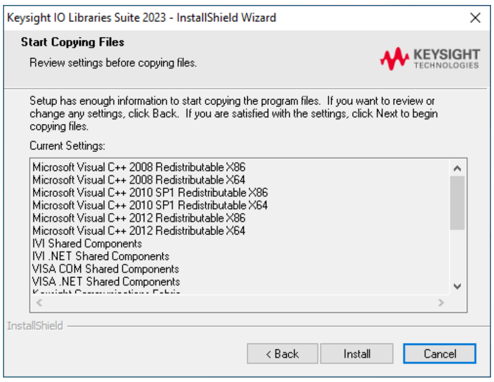

Figure 61: Keysight IO Libraries Suite 2023

D.1.3 Rohde & Schwarz VISA

Rohde & Schwarz VISA 5.12.8 is the minimum required version by METAS VNA Tools. Make sure that R&S VISA.NET 64/32-Bit is selected in the installation process, see figure 62.

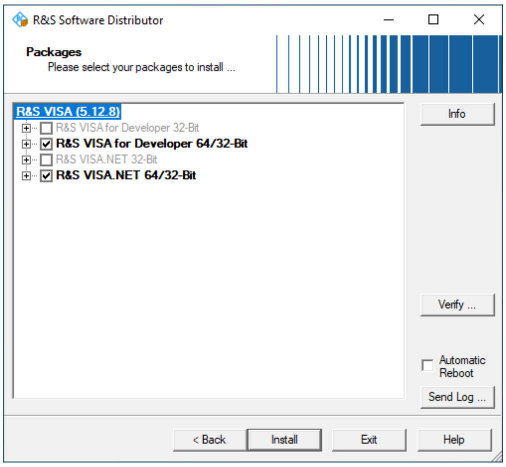

Figure 62: Rohde & Schwarz VISA 5.12.8

D.2 Driver Development

For VNA's, switch drivers and electronic calibration units that are not supported yet, the user has the possibility to develop custom drivers that can be used with METAS VNA Tools. This section describes the development of such drivers. The minimum software requirements for driver development in Microsoft Visual Studio for METAS VNA Tools are:

- METAS VNA Tools, www.metas.ch/vnatools
- National Instruments VISA 19.0, www.ni.com/visa
- Microsoft Visual Studio 2012 or newer, www.visualstudio.com

The step by step procedure for the development of a custom driver for a VNA is as follows:

1. Check if the environment variable called `%Public%` is defined. This is the case under Microsoft Windows Vista and 7 but not under XP. Under Microsoft Windows XP you have to set the `%Public%` variable to `C:\DocumentsandSettings\AllUsers`.
2. Make sure the driver template `Metas.Instr.Driver.Template.zip` is in the template folder of Visual Studio under `%Userprofile%\Documents\VisualStudio20xx\Templates\ProjectTemplates`. Otherwise copy it from `%Public%\Documents\Metas.Instr\Drivers`.
3. Launch Microsoft Visual Studio.
4. Create new project from template in Visual Studio under File / New Project / My Templates / Metas.Instr.Driver.Template and name the project e.g. 'MyFirstVNA'.
5. Add a new class to the project under Project / Add Class and name it e.g. 'MyFirstVNA'.
6. This step describes the programming of the driver. Declare the class as public and implement the 'Metas.Instr.Driver.Vna.IVna' interface. See Figure 63 and MSDN website for how to implement an interface.
7. Compile project under Build / Build Solution. Make sure that the post-build event is successful and that the `MyFirstDriver.dll` is copied to `%Public%\Documents\Metas.Instr\Drivers`.
8. Test your driver directly in METAS VNA Tools or debug it in Microsoft Visual Studio under Debug / Start Debugging.

For more help take a look at the already implemented drivers for METAS VNA Tools under `%Public%\Documents\Metas.Instr\Drivers\Source`.

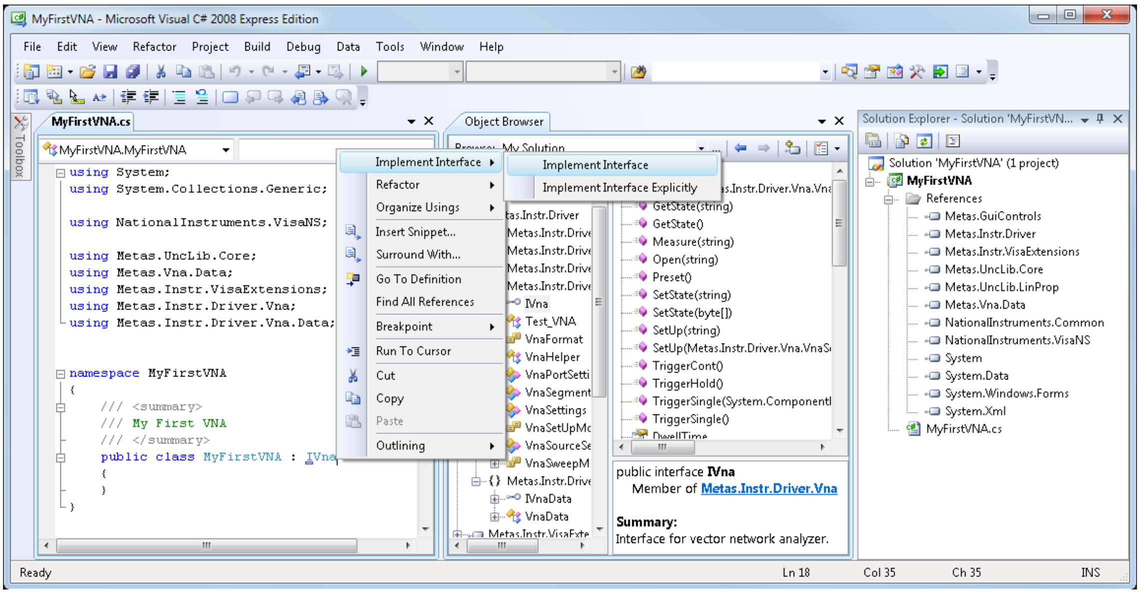

Figure 63: MyFirstVNA - Microsoft Visual Studio: Clicking with the right mouse button on IVna opens a content menu. Clicking on the menu item Implement Interface will create the basic class structure with all necessary properties and methods for the new driver.

E Switch and Error Terms

The switch terms $\mathbf{W}$ and error terms $\mathbf{E}$ of a calibration can be visualized using the Data Explorer of VNA Tools by expanding a calb-file, see figure 64.

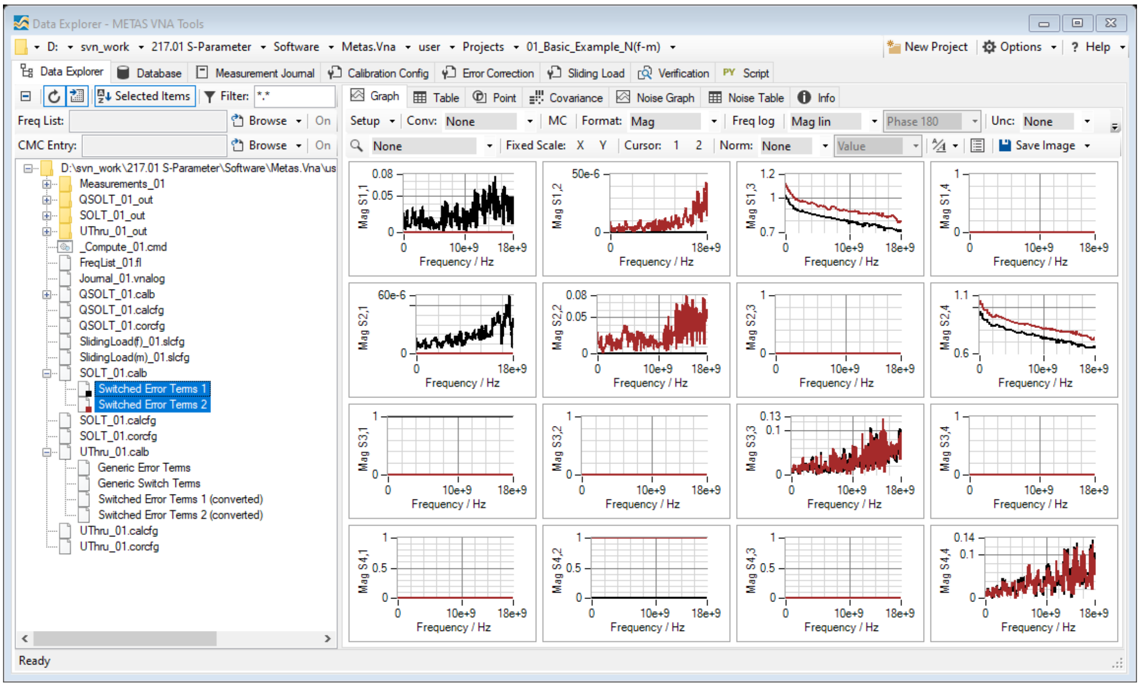

Figure 64: VNA Tools / Error Terms

The following S-parameter matrix describes the calibration error terms $\mathbf{E}$ of a N-port VNA.

$$\begin{pmatrix}
D_1 & X_{1,2} & & X_{1,N} & T_{1,} & & & \\
X_{2,1} & D_2 & & X_{2,N} & & T_{2,} & & \\
 & & \ddots & & & & \ddots & \\
X_{N,1} & X_{N,2} & & D_N & & & & T_{N,} \\
T_{,1} & & & & M_1 & & & \\
 & T_{,2} & & & & M_2 & & \\
 & & \ddots & & & & \ddots & \\
 & & & T_{,N} & & & & M_N
\end{pmatrix}$$

D_x denotes the directivity of port x.

$X_{y,x}$ denotes the crosstalk from port x to port y.

$T_{x,x} = T_{x,}T_{,x}$ denotes the reflection tracking of port x.

$T_{y,x} = T_{y,}T_{,x}$ denotes the transmission tracking from port x to port y.

M_x denotes the match of port x

and all other terms are additional crosstalk terms.

E.1 Generic Model

In the generic model the switch terms $\mathbf{W}$ are stored in a N-port and the error terms $\mathbf{E}$ are stored in a $2N$-port for a N-port VNA. For a 2-port VNA this would result in a 2-port switch term network and a 4-port error term network or 4 switch terms and 16 error terms. The generic model is applied independently of the source setting of the VNA. As a consequence, the 7-term model can be represented by the generic model by setting some error terms to zero.

The following table shows the switch terms $\mathbf{W}$ of the generic model of a 2-port VNA:

Table 11: Switch Terms

W_{11}: Switch term of port 1 (source switched to port 2)	W_{12}: 0
W_{21}: 0	W_{22}: Switch term of port 2 (source switched to port 1)

The following table shows the error terms $\mathbf{E}$ of the generic model of a 2-port VNA:

Table 12: Generic Error Terms

E_{11}: Directivity of port 1	E_{12}: Crosstalk from port 2 to port 1	E_{13}: Tracking	E_{14}: 0
E_{21}: Crosstalk from port 1 to port 2	E_{22}: Directivity of port 2	E_{23}: 0	E_{24}: Tracking / Symmetry
E_{31}: 1	E_{32}: 0	E_{33}: Match of port 1	E_{34}: 0
E_{41}: 0	E_{42}: Symmetry	E_{43}: 0	E_{44}: Match of port 2

The generic error terms $\mathbf{E}$ and the switch terms $\mathbf{W}$ can be converted to the switched error terms. This can be used for comparisons of calibrations.

E.2 Switched Model

In the switched model the error terms $\mathbf{E}^i$ are stored in a $2N$-port for each switch position i for a N-port VNA. For a 2-port VNA this would result in two 4-port error term networks or 32 error terms. The switched model is applied dependently of the source setting of the VNA. As a consequence, the 12-term model can be represented by the switched model by setting some error terms to zero. This model is used for the SOLT calibration.

The following table shows the forward error terms $\mathbf{E}^F$ (switched error terms 1, source switched to port 1) of a 2-port VNA:

Table 13: Forward Error Terms

E^F_{11}: Directivity of port 1	E^F_{12}: 0	E^F_{13}: Reflection tracking of port 1	E^F_{14}: 0
E^F_{21}: Crosstalk from port 1 to port 2	E^F_{22}: 0	E^F_{23}: 0	E^F_{24}: Transmission tracking from port 1 to port 2
E^F_{31}: 1	E^F_{32}: 0	E^F_{33}: Source match of port 1	E^F_{34}: 0
E^F_{41}: 0	E^F_{42}: 0	E^F_{43}: 0	E^F_{44}: Load match of port 2

The following table shows the reverse error terms $\mathbf{E}^R$ (switched error terms 2, source switched to port 2) of a 2-port VNA:

Table 14: Reverse Error Terms

E^R_{11}: 0	E^R_{12}: Crosstalk from port 2 to port 1	E^R_{13}: Transmission tracking from port 2 to port 1	E^R_{14}: 0
E^R_{21}: 0	E^R_{22}: Directivity of port 2	E^R_{23}: 0	E^R_{24}: Reflection tracking of port 2
E^R_{31}: 0	E^R_{32}: 0	E^R_{33}: Load match of port 1	E^R_{34}: 0
E^R_{41}: 0	E^R_{42}: 1	E^R_{43}: 0	E^R_{44}: Source match of port 2

F Further Reading

Documentations

- VNA Tools - User Manual
- VNA Tools - Math Reference
- Data Explorer - User Manual

Presentations

- VNA Tools - Overview
- VNA Tools - S-Parameter Uncertainty Calculation
- VNA Tools - Data Format
- VNA Tools - Optimization Calibration
- VNA Tools - Step Attenuator Measurement
- VNA Tools - Splitter Measurement

Tutorials and Screencasts

- VNA Tools - Tutorial: Perform a SOLT Calibration with the Test VNA.

Calibration Guidelines

- Guidelines on the Evaluation of Vector Network Analysers (VNA)
  www.euramet.org/publications-media-centre/calibration-guidelines

Websites

- www.metas.ch/vnatools
- www.metas.ch/unclib