Software Manual

Virtual Embedding Networks

ZVR-K9

1106.8830.02

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Basics

Measuring Tasks

A frequently occurring category of measuring tasks in network analysis comprises the so-called embedding and de-embedding problems. A device under test (DUT) is embedded if its ports are all connected to a transformation network (TN) so that only the ports of the transformation network are accessible from outside. This transformation network may be e.g. a matching circuit, a test fixture or a case. In general, it features twice as many ports as the DUT. The ports of the transformation network which are connected to the device under test are referred to as "inner" ports, those accessible from outside as "outer" ports. Fig. 1 shows an example of a two-port embedded in a transformation network with four ports.
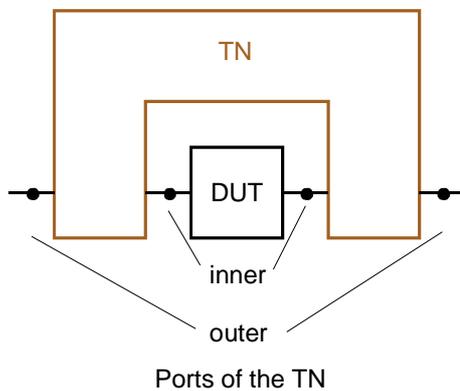
Fig. 1:   Inner and outer ports of a transformation network

One possible measuring task consists of measuring the really existing DUT such as if it were embedded in a transformation network, although the latter is physically not existing. In this case, virtual embedding is involved. Fig. 2 shows the example of a measurement of a DUT with the input and output impedance Z_1, which is provided with virtual impedance transformers from Z_1 to Z_0 and is thus matched to the reference impedance Z_0 for the measurement.

Fig. 2:   Virtual impedance matching

In the opposite case, the device under test is inseparably connected with the transformation network, i.e. the ports of the DUT are not accessible. If, nevertheless, the S-parameters of the DUT alone are to be determined, a "de-embedding" problem is involved. This measuring problem can be reduced to the embedding problem by embedding the real combination of DUT and transform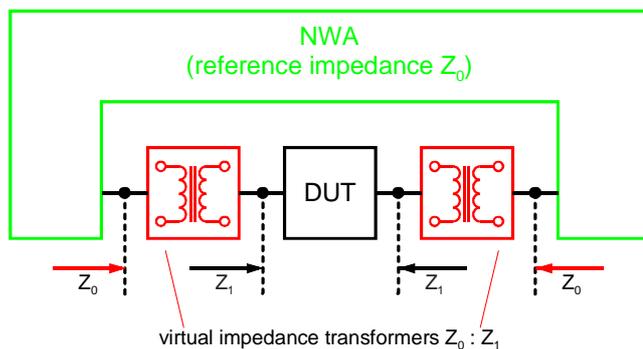ation network into the virtual inverse transformation network. The inverse and the real transformation network cancel each other so that, viewed from outside, only the DUT is left (Fig. 3).
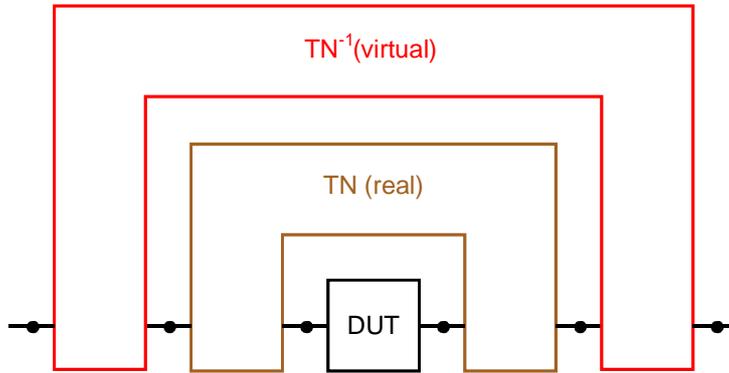

Fig. 3: Reducing the de-embedding problem to the embedding problem

A third type of measuring task consists of the determination of the S-parameters of an unknown, but physically existing transformation network. In the case of the two-port measurement, the difficulty is based on the fact that the network is a four-port and, therefore, cannot directly be measured. Also the inner and outer ports often differ in the type of transmission line (e.g. in the case of a test fixture for SMD components), which makes the calibration for a direct measurement more difficult. Measuring tasks like that are often referred to as *Unterminating* problems.

Approach

The solution to embedding and de-embedding problems known so far consists of importing the S-parameters of the really existing DUT measured with a network analyzer into a CAD program and embedding them there in a simulated circuit environment. In addition to the network analyzer, a controller on which the CAD program runs is generally required. The data transmission is in most cases effected via IEC bus. This procedure can hardly be performed in automatic mode, since each simulation requires manual user operations. Due to the data transmission and computing times, a real-time indication, e.g. for adjustment of the DUT, is not possible.

In this case, the Software Option ZVR-K9 of the Network Analyzer ZVR offers clear advantages. The idea is to consider the virtual transformation network in the system error correction data of the network analyzer. Since a system error correction is performed anyway for almost all measuring tasks, no additional stage of processing is required. Besides, there is no data transmission to an external controller. Thus, the measurement with a virtual transformation network is as fast as the measurement without one, real-time adjustment of the DUT is possible.

The S-parameters of the transformation network originate either from a CAD program or from a measurement. The transformation network is not directly measured, but by forming the difference between calibrations at the inner and outer ports. This avoids the through-connection between ports of different types of transmission lines which would be required in the calibration for a direct measurement.

System Requirements

In order to use all features of the software option ZVR-K9, *Virtual Embedding Networks,* a Network Analyzer ZVR, ZVC ZVM or ZVK is required. This manual only refers to the model ZVR, however, all that is said also applies to ZVC, ZVM and ZVK. ZVR-K9 version 2.1 runs under Microsoft Windows$^{®}$ 3.1 or NT 4.0, for version 3.1 Windows NT 4.0 is required. On older instruments ZVR with stock no. 1043.0009.xx and ZVC with stock no. 1106.9020.xx, Windows 3.1 is part of the option ZVR-B15 (Controller). Connection of an external keyboard to the ZVR is necessary, a mouse considerably facilitates operation as with all Windows applications. For Windows 3.1, the version number of the ZVR firmware must be 1.70 or higher, for Windows NT it must be 3.04 or higher. The version number can be polled via *INFO: FIRMWARE VERSIONS.*

If one ist only interested in the functions of the File menu, that is import, export and administration of transformation networks, one may, as well, install ZVR-K9 version 3.1 on a PC under Windows 95/98/NT4.0.

Important Note:

> If ZVR-K9 runs under Windows 3.1, the files
>
> > **D:\RUNTIME\RSIB\RSIB.DLL** and
> > **D:\RUNTIME\RSIB\RSDDE.DLL**
>
> must be copied to the directory
>
> > **C:\WINDOWS\SYSTEM**
>
> before starting the application for the first time!

Installation

The software option ZVR-K9 is supplied on two installation disks. For an installation on a ZVR, the key code number, which can be found on the sheet "software installation", is additionally required. You may also obtain this number from your R&S representative.

1. (only for installation on a ZVR) Enter the key sequence *SETUP: OPTIONS: ENABLE NEW OPTION* on the ZVR. The input field for optional key codes will then be opened. Enter the key code number for the option ZVR-K9. If the input is correct, the message "OPTION KEY OK" will appear, otherwise "OPTION KEY INVALID".

2. (only for installation on a ZVR) Switch the ZVR from measurement screen to PC screen by simultaneously pressing the keys *Alt* and *Sys Rq* on the external keyboard.

3. Insert installation disk no. 1 into the disk drive.

Windows 3.1 (only in the case of installation on a ZVR):

4. Start Windows by entering *WIN.*

5. Select the command *Run* from the *File* menu in the Windows program manager.

6. Enter the following text in the *command line*:   ***a:\setup***

Windows NT:

4. Select the command *Run* from the Windows *Start* menu*.*

5. Enter the following text in the *Open* field: ***a:\setup***

7. Select *OK.*

8. Follow the instructions on the screen.

The Setup program automatically creates all the necessary directories. You may determine the name of the program group for ZVR-K9 and the de-installation program. After the installation has been terminated, this program group is in the foreground.

Getting Started

For installation of the Software ZVR-K9, a virtual transformation network generated with the aid of a CAD program is included. This network permits to illustrate some of the numerous possible applications of this software option.

Preparation

Reset the ZVR to a predefined default status using *PRESET* and perform a full two-port user calibration according to the TOM method over the complete frequency range. After calibration, establish a through-connection (THROUGH) between the test ports PORT 1 and PORT 2. Use the key combination *Alt + Sys Rq* to switch over to PC operation and start Windows. Then start the application ZVR-K9 in the program group with the same name.

First, only the main menu and the status line are visible at the lower edge of the screen. The left-hand field of the status line displays the currently active input function or the current action of the program, the right-hand field indicates the user prompts.

Importing a File Generated by a CAD Program

The demo network is provided in the data base format of Ansoft (e.g. Serenade®) under the name *GETSTART* in the directory *c:\rsapplic\demo*. To be able to use it, import and save it in the specific data format of the Software ZVR-K9. For this purpose, use the command *Import Network* in the *File* menu. It opens a window having the same name. Within the frame *Select File* on the left-hand side, select the file *GETSTART.FLP*. Then click on the box *TN1 THROUGH* in the graph. The box will turn red and the frame *Select Action* will appear below. In the frame, select *Insert Selected File*. Now the format of the import file will be checked. The following question may be answered by *YES* or *NO*, since the right subnetwork TN2 of *GETSTART.FLP* is just an ideal through, too. Now the box TN1 displays the file name instead of *THROUGH*. Click on *Import Network(s)*. Then follows the window *Save Transformation Network* for entering the name of the network and an optional comment with up to 256 characters. The *Network List* indicates all networks stored so far for info. By clicking on *OK*, the new network file will be stored in the ZVR-K9 format, thus completing the file import.

Storing the Calibration

Next, the imported network is to be considered in the previously created user calibration, i.e. the latter is modified. It is recommended to store the original calibration status if you intend to reuse it later. For the management of calibration data, the command *Cal Manager* is provided in the main menu, calling up an interactive window. The keypad *Append Active Cal to List* permits to store the currently active user calibration in the *Cal List*. You may define a name with a length of up to 8 characters for this calibration. Vice versa, a calibration can be reactivated from the *Cal List* via *Set Cal Active*. In addition, the *Cal Manager* permits you to determine in which calibration (*Base Cal*) a network is to be considered. The current setting is indicated on the left side in the frame *Base Cal for (De-) Embedding*. You may define either the current calibration or the one selected in the *Cal List* as *Base Cal*. Even if you have transferred the previously created user calibration into the *Cal List*, it remains active and you may maintain the default setting of the frame *Base Cal for De-(Embedding)*. The key *Close* permits to leave the *Cal Manager*.

Including a Network in a Calibration

Call up the command *Embedding* in the main menu. The window displayed shows you the frame *Base Cal* with the base calibration set in the *Cal Manager*, into which the network is embedded. The *Network List* in the lower half of the screen lists all currently stored networks. Next to the name, you can see the most important data at a glance, such as date, comment, point grid and frequency range. If the list contains many entries, you will be able find the desired network faster with these additional pieces of information. If you have installed the Software ZVR-K9 and performed all steps described so far, the network list only contains the previously imported *getstart*. Select this network by clicking on the relevant line. The name will then appear in the frame *Embedding Network* and the key *Modify Base Cal* can be operated. Click on this key. After successful termination of embedding an appropriate message will appear. Confirm this message and return to the main menu.

Result

You may have noticed in the last step that the status LED *REM(OTE)* was switched on as long as the window *Embedding* was open. This LED indicates that the ZVR is under the control of the Software ZVR-K9. In the main menu, however, this LED is always switched off. You may then switch over to measurement screen and operate the ZVR via the front panel. Switch to measurement screen now and activate the four-channel display (*DISPLAY: QUAD CHAN QUAD SPLIT*). You will then see all the four S-parameters of your device under test - the through-connection - as if it were embedded into a virtual network. This virtual network consists of an ideal bandpass filter at PORT 1 and an ideal through-connection at PORT 2. Thus, only the S-parameters of the bandpass filter with a passband of 1.2 to 1.5 GHz take effect (Fig. 4).
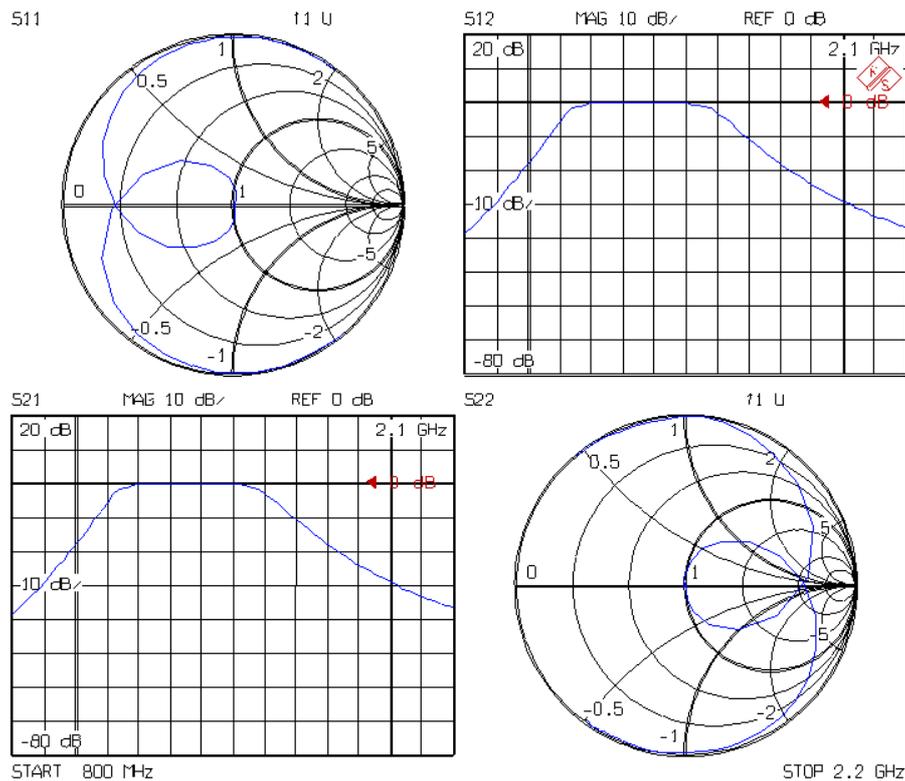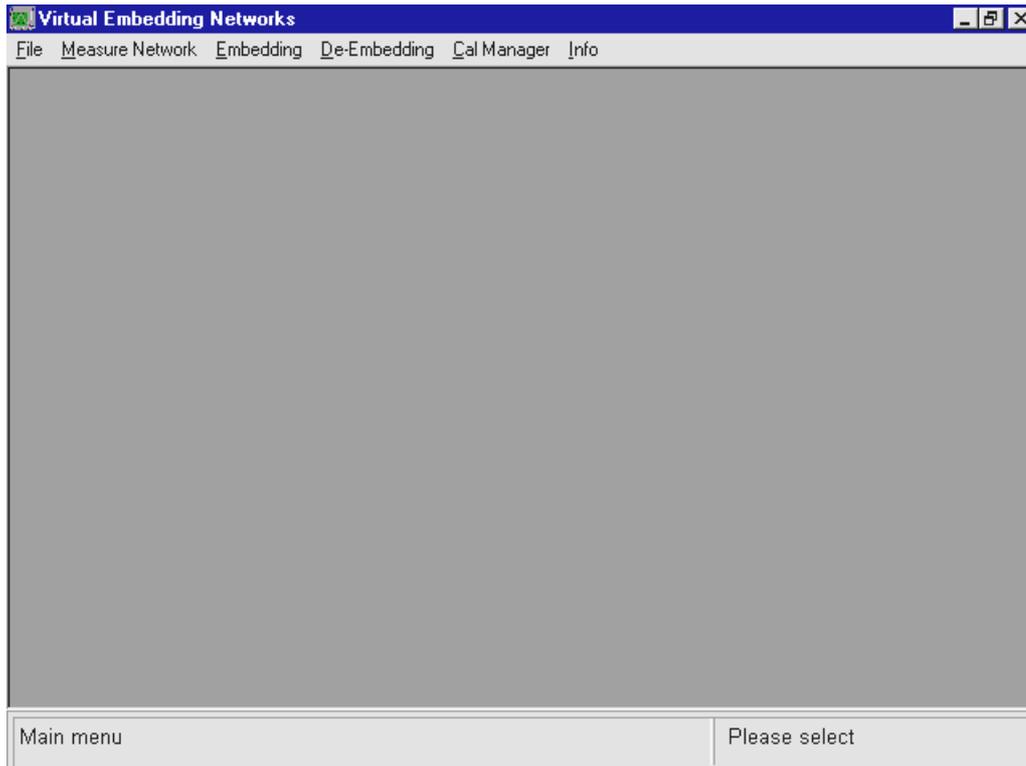

Fig. 4:   Scattering parameters of virtual network *getstart*

When the base calibration is modified, frequency range and point grid of the virtual network are adopted. This is why the frequency range has also changed compared with the previous status after *PRESET*.

Further important functions are the measurement of a transformation network and the data export in CAD file format. This will be explained in more detail in the sections "Menu Overview" or "Application Examples".

Menu Overview

In this section, all functions are listed according to their order in the **main menu**.

Virtual Embedding Networks				_	□	×

File Measure Network Embedding De-Embedding Cal Manager Info

Main menu   Please select

When a command is called up from the main menu, the network analyzer changes to the REMOTE status. Thus only in the main menu can the ZVR be operated via the front panel after switchover to the measurement screen by means of the key combination *Alt + Sys Rq*.

> **Attention:** *This Windows application controls the ZVR via the DDE interface. This is why the network analyzer can not be controlled via IEC/IEEE-bus while ZVR-K9 is active.*

File

This command opens a submenu containing the functions for the data transfer between ZVR-K9 and CAD programs as well as for the management of transformation networks. Furthermore, the system configuration (hardware platform) may be defined here. The Software ZVR-K9 can also be left via *File*. This menu is available even when ZVR-K9 has been installed on a PC.

Import File

The function *Import File* permits to import files which contain the S-parameters of virtual networks in the data format of CAD programs. This function can be used e.g. to design ideal transformation networks in a CAD program and import their S-parameters as a network. Likewise, it is possible to export a measured network, process it in a CAD program and import the modified network back to the Software ZVR-K9.

Supported are the data base formats of Ansoft/Compact Software (e.g. Super Compact®, Serenade®) with the file name extension .flp and of Agilent EESof EDA (Touchstone®, Series IV®, ADS®) with the extension .s4p. An example of the flp.format is the file *getstart.flp* in the directory *c:\rsapplic\demo*.

When importing the S-parameters of a transformation network, the correct definition of the port numbers is crucial. For four-ports numbering is sequential from left to right (Fig. 5)
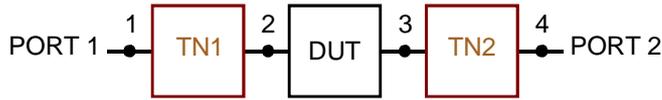

Fig. 5:   Numbering of the ports of the transformation network

> ***Caution:***   *It is very important to observe the assignment of the ports in order to avoid faulty results.*

A possible coupling of the sub-two-ports TN1 and TN2 is not taken into account, i.e. the upper right and the lower left (2x2) sub-matrix of the four-port S-matrix is taken to be zero. To avoid singularities, the four-port S-parameters S_{12} and S_{43} must be different from zero, i.e. the two-ports TN1 and TN2 transmit in at least one direction.

Alternatively, one may compose the transformation network of two different two-port files. In this case, port 1 of TN1 and TN2 is always oriented towards the device under test, which requires the parameter S_{21} to be different from zero. Furthermore, it is also possible to import a sub-two-port of a four-port.

In addition, one-port reflection factors may be imported as well. The reflection factor is interpreted as S_{11} and S_{22} of a symmetric two-port, which has an ideal transmission factor equal to 1.

Before completing the import of the transformation network one may modify its sub-two-ports. A two-port may be turned to reverse orientation or replaced by an ideal through-connection.

The point grids of the files to be imported must be either linear or logarithmic and must coincide for the two sub-two-ports. The reference impedances of the sub-two-ports must be identical, too. Besides, for files in the Ansoft format, it is checked whether the point grid data in the file header is consistent with the actual data set in the file body.

All complex data formats supported by the aforementioned CAD programs are recognized. These are magnitude and phase, magnitude in dB and phase as well as real and imaginary part. Permissible units for frequency indications are Hz, kHz, MHz and GHz.

Detailed procedure:

Window **Import Network**:
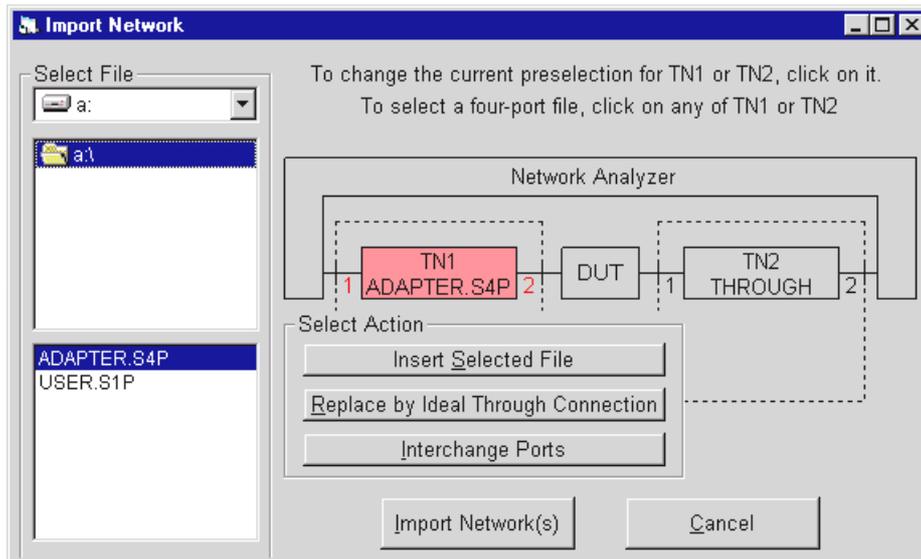
The frame *Select File* enables one to select path and name of the file to be imported. Only files with the extension .flp (Ansoft format) or .snp (Agilent-EESof format, n = 1, 2 or 4) are displayed. A transformation network is always a four-port that consists of the two sub-two-ports TN1 and TN2. These two-ports can be configured independently. This is accomplished by clicking on either box TN1 or TN2, which makes the selected box turn red and opens the frame *Select Action*. TN1 and TN2 are pre-defined as through-connections, in this case only the keypad *Insert Selected File* is available. Clicking on it, the format of the file selected in the frame *Select File* is examined. After this check has been passed, the name of the selected file, instead of *THROUGH*, appears in the box. Otherwise, a message box indicates which error has been found in the format.

If a four-port is to be imported, one may click on either of TN1 or TN2. The user is prompted to decide whether the complete four-port should be read or just the selected sub-two-port.

After having pre-selected a file, the other two keypads in the frame *Select Action* will become available, too. *Replace by Ideal Through Connection* restores the original state, i.e. an ideal through connection is assumed for the selected two-port. *Interchange Ports* interchanges port 1 and port 2 of the two-port, which means that S_{11} and S_{22}, as well as S_{12} and S_{21}, swap their places in the S-matrix. In the graph the port numbers are interchanged.

The sub-two-ports TN1 and TN2 may be modified as often as desired. When the final configuration has been found, the actual file import is started via the keypad *Import Network(s)*. The progress of the three calculation steps that are performed is indicated by a bar in the status area.

The next window that follows is **Save Transformation Network**:
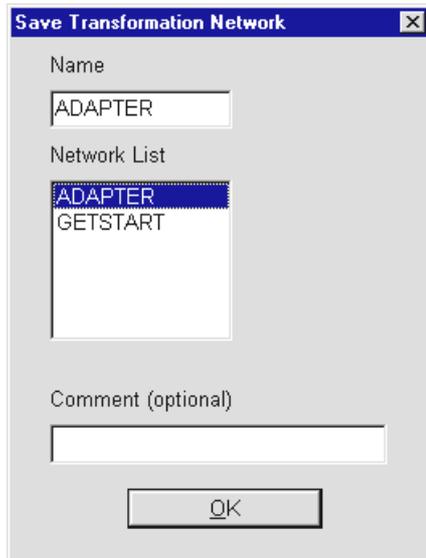
The field *Name* permits to specify the name under which the imported data are stored as a virtual network. This name must comply with the DOS convention for file names, but it features no extension. No differentiation is made between upper-case and lower-case letters. The *Network List* lists all networks stored so far. The field *Comment* permits to enter an optional comment consisting of up to 256 characters. This additional information will then appear in the detailed network list under the command *Embedding*. The keypad *OK* completes the file import.

Export Network

The function *Export Network* is used to output the S-parameters of virtual networks in an ASCII data format which can be imported by CAD programs. Supported are the data base formats of Ansoft/Compact Software (e.g. Super Compact®, Serenade®) with the file name extension .flp and of Agilent-EESof (Touchstone®, Series IV®, ADS®)) with the extension .snp (n = 2 or 4). This function permits e.g. to import measured transformation networks into a CAD program for analysis or modification.

One may either export the complete transformation network as a four-port or one of the sub-two-ports. Anyway, the port numbering described under *Import Network* holds.

The computation of the transformation networks is based on the 7-term calibration techniques where the four transmission parameters of the sub-two-ports are normalized. The normalization causes the values of the individual transmission coefficients of TN1 and TN2 to be changed. The calculation of the S-parameters of an embedded device under test remains unaffected by this normalization, since for this only the products of transmission parameters, which are invariant with respect to normalization, are used. If one knows that one of the two sub-two-ports is reciprocal, its transmission parameters can be adequately unnormalized for export. If both are reciprocal, it is sufficient to define one side as reciprocal, the other side will then also be correctly exported.

For exporting the networks, all data formats supported by the CAD programs mentioned above are offered.
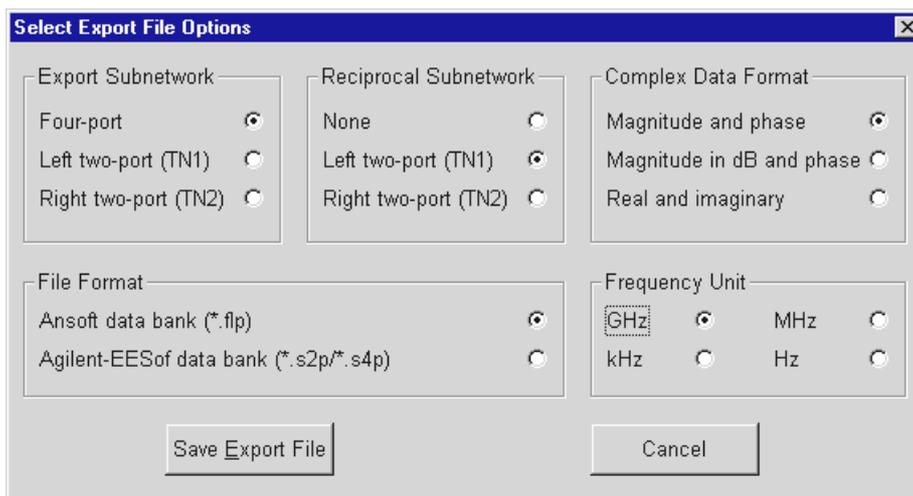
Detailed procedure:

Window **Export Network**:
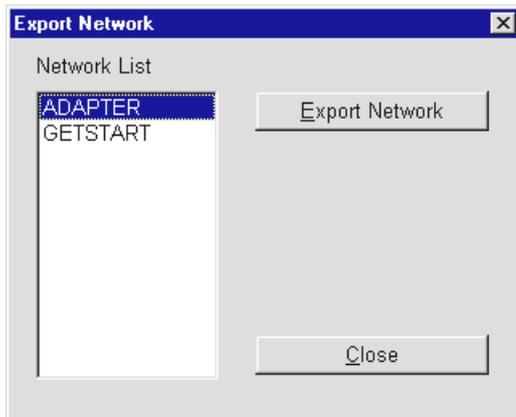
The Network List lists all networks stored. Set the selection bar to the network to be exported and select the keypad *Export Network*.

Window **Select Export File Options:**

This window is used to determine the options for data export. Within the frame *Export Subnetwork,* one can decide whether the complete transformation network is to be exported or just a sub-two-port. The frame *Reciprocal Subnetwork* allows the user to determine whether and how the unnormalization of the transmission parameters shall be performed. The frame *File Format* permits one to choose either the Ansoft (formerly: Compact Software) or the Agilent-EESof format. The output format for the complex S-parameters is selected in the frame *Complex Data Format*. It is possible to choose between magnitude and phase, logarithmic magnitude (in units of dB) and phase as well as real and imaginary part. Finally, the frequency unit can be selected in the frame *Frequency Unit*. Here, the possible units are GHz, MHz, kHz and Hz. Having defined all options select the keypad *Save Export File*.

The frequency values and S-parameters are stored with an accuracy of 7 digits after the decimal point.

Window *Save Export File*:
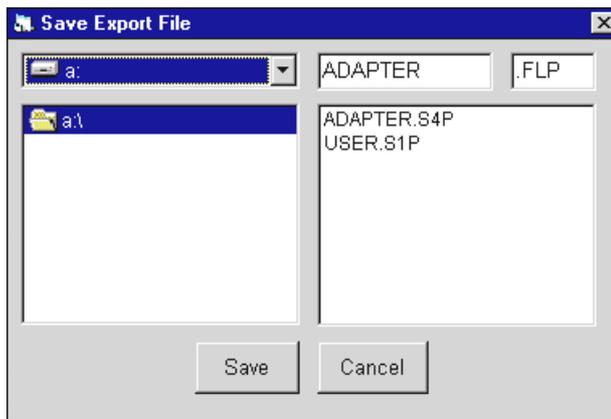
This window is used to determine the path and the name of the file to be exported. According to the data format selected before, a file name extension is determined automatically. *Save* starts the storage procedure. Its successful termination is indicated by a message that is to be confirmed by the user.

Network Manager

The window *Network Manager* is used for the management of transformation networks.
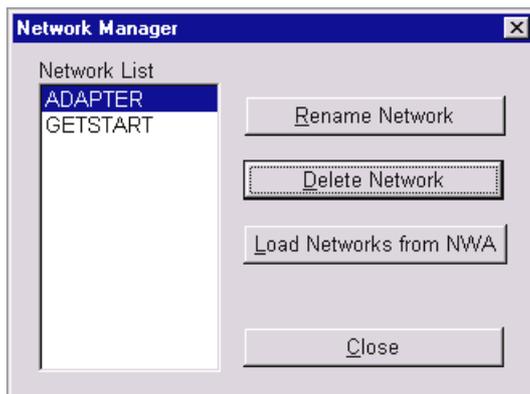
Transformation networks can be renamed, deleted or loaded from the ZVR into the controlling computer. The *Network List* on the left lists all stored networks. The desired network can be selected using the selection bar. To rename a network press the keypad *Rename*, which will open a field for entering the new name. Network names must comply with the DOS convention for file names, but do not contain any extension. The keypad *Delete* deletes the selected network. For the LAN Configuration (see Window *Hardware Configuration*), the keypad *Load Networks from NWA* is available, too. It opens a window having the same name.
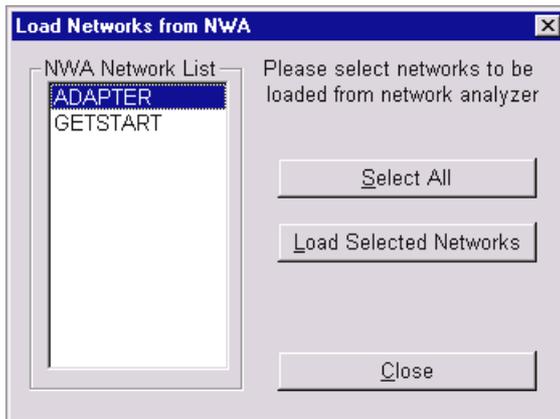
This window is useful for copying transformation networks from the ZVR to the controlling computer. The *NWA Network List* shows the networks that are stored in the ZVR, choose those which are to be copied by means of a selection bar. *Select All* selects the whole list. *Load Selected Networks* loads all selected networks into the controlling computer. The window is closed via *Close*.

Hardware Configuration*:*

The window ***Hardware Configuration*** allows the user to specify the hardware platform for the software ZVR-K9:
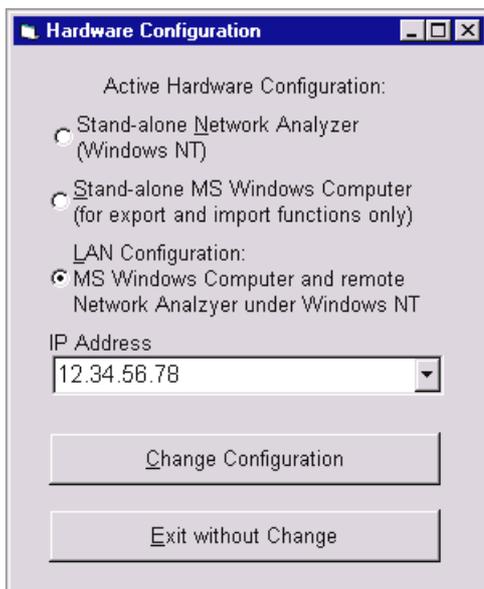
If the software ZVR-K9 runs on a ZVR under Windows NT, choose *Stand-alone Network Analyzer*.

ZVR-K9 can also be run on a Windows PC, in this case the option *Stand-alone MS Windows Computer* must be selected. For this configuration, however, the main menu contains only the *File* and *Info* submenus, thus only transformation network management functions are available.

If the ZVR is connected to a computer network via an Ethernet adapter (option FSE-B16), the ZVR-K9 software may also be started from any Windows computer in the network. In this case, choose the *LAN Configuration* option, then all functions of ZVR stand-alone operation are available. Enter the IP address of the ZVR into the *IP Address* field using the format 12.34.56.78. Note that calibration data (*Cal List*) are always related to the network analyzer and thus kept in it, whereas transformation networks (*Network List*) are stored in the controlling computer. If there are transformation networks on the ZVR, they may be copied to the controlling computer by means of the function *Load Networks from NWA* (see *Network Manager*). A special case of the *LAN Configuration* should be mentioned, which is stand-alone

operation of a ZVR. In this case, ZVR-K9 running on the network analyzer controls the analyzer via ist own IP address.

As long as the *Hardware Configuration* window is open, configuration changes do not yet become effective. It is the *Change Configuration* keypad that accepts the selected configuration and quits the window. If no change is desired, one may return to the main menu via the keypad *Exit without change*.

Exit

The command *Exit* terminates the Software ZVR-K9.

Measure Network

This command can be used to measure transformation networks (*Unterminating* problem). This is particularly useful if the network to be virtually considered later is physically present (e.g. test fixture, component case) but be designed via CAD with sufficient accuracy. The scattering parameters of the network can be determined by carrying out a calibration at the outer and inner ports and by forming the difference between the respective error four-ports. This procedure can be used if both the outer and the inner ports are directly accessible.

In some cases, however, the desired transformation network is inseparably connected with an auxiliary network. If the auxiliary network alone (e.g. a test fixture without transformation elements) is also physically existing, a two-stage procedure permits to determine first the auxiliary network and the auxiliary network plus transformation network and finally the transformation network itself by means of three calibrations. This case is referred to as "indirect access". As a prerequisite, the outer ports of auxiliary network and auxiliary network plus transformation network must feature the same connector type so that one common outer calibration is sufficient.

Inner and outer calibrations, on the other hand, do not necessarily refer to the same connector type. For example, test fixtures for non-coaxial components (SMD cases etc.) with coaxial outer connectors can also be measured. For non-coaxial inner calibrations, 7-term self-calibration techniques are recommended, such as e.g. TRL, TRM or TNA, which do not require all standards to be completely known.

The two partial two-ports TN1 and TN2 as well as, if applicable, the auxiliary networks AN1 (= **A**uxiliary **N**etwork **1**) and AN2 must be transmitting. To avoid numerical inaccuracies, the transmission loss should not exceed 50 dB.

Detailed procedure:

Before calling up *Measure Network*, frequency range, point grid and other desired sweep settings for the calibration measurements must be set via the front panel of the ZVR. The main menu permits to switch between measurement and PC screen using the key combination *Alt + Sys Rq*.

Window *Access to Transformation Network*
(called up by the command *Measure Network* in the main menu):
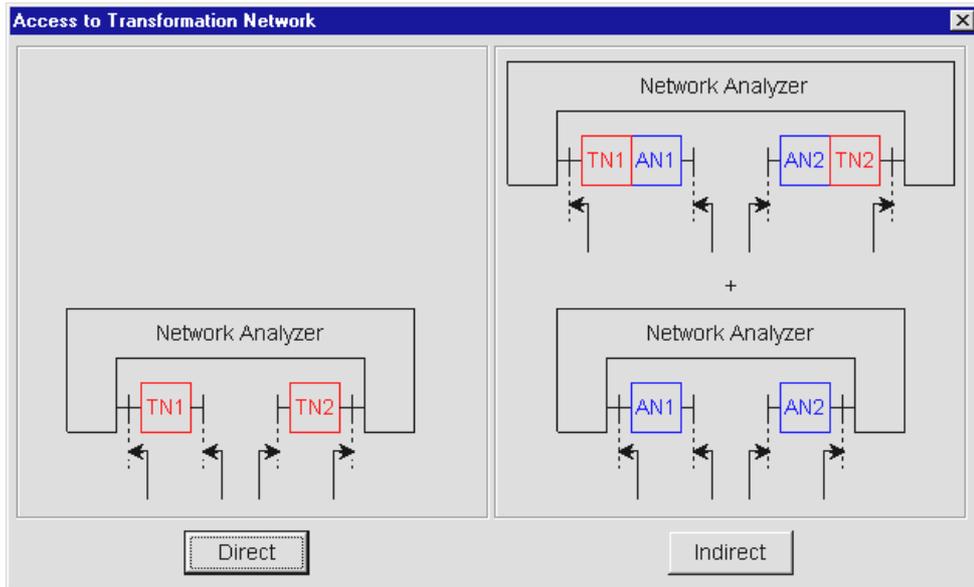

This window permits to determine whether the transformation network to be measured is directly accessible (keypad *Direct*) or connected to an auxiliary network (keypad *Indirect*). Both cases are illustrated by graphs showing the reference planes for inner and outer calibration.

In the case of indirect access, the assumption is made that the transformation network is connected to the outer ports of the combination transformation/auxiliary network. Thus it can be taken into account in the system correction data of the NWA later. As all this represents only a model, it is irrelevant whether the real transformation and auxiliary networks are actually connected in series as described above.

Window *Direct Measurement*
(called up via keypad *Direct* in the window *Access to Transformation Network*):
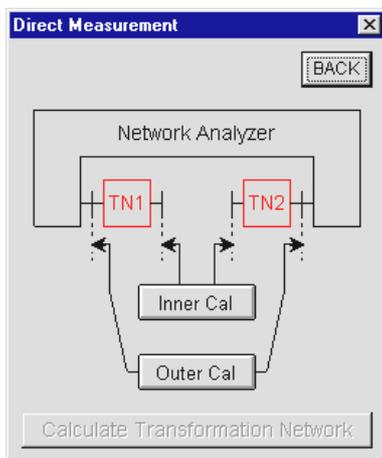
This window permits to start inner (keypad *Inner Cal*) and outer calibration (keypad *Outer Cal*) as well as the final computation of the transformation network. The order of inner and outer calibration is arbitrary. The keypad *Calculate Transformation Network*, however, can only be operated after both calibrations have been performed. The *BACK* button leads back to the previous window. This button is also available in most of the windows described in the remainder of this section. Within the *Measure Network* menu, the order in which the windows are called up is stored, so it is possible to return to the previous windows by pressing the *BACK* button repeatedly.

Window ***Direct Inner Calibration: Cal Source***
(called up via keypad *Inner Cal* in the window *Direct Measurement*):
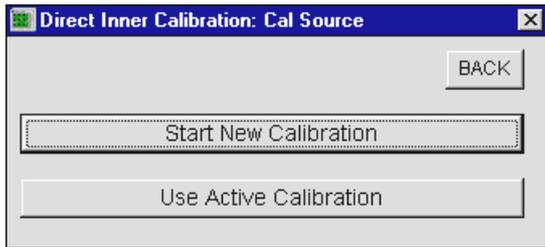
This window permits the user to choose between using the currently active calibration of the ZVR as inner calibration (keypad *Use Active Calibration*) and performing a new calibration (keypad *Start New Calibration*). If you select the currently active calibration, this is restored with the original sweep settings valid when this calibration was performed. The same is true if the calibration was switched off. Thus, point grid, generator level, internal/external operating mode, etc. may change. If an outer calibration already exists, it becomes invalid. These sometimes undesired results of the function *Use Active Calibration* are indicated in a message window which is to be confirmed by the user and from where the function can be aborted.

Window ***Inner Calibration: Define Connector and Cal Method***
(called up via keypad *Start New Calibration* in the window *Inner Calibration*):
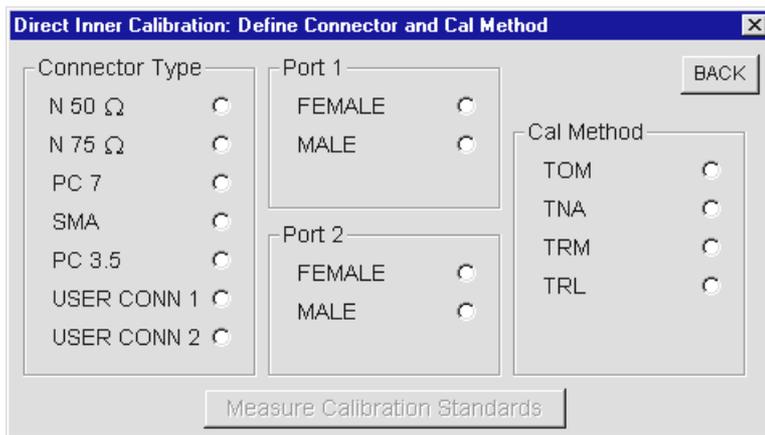
This window permits to determine connector type and sex of the test ports as well as the calibration method for the inner calibration. When the ZVR is operated via the front panel, these parameters are polled in successive menus. One of the four 7-term techniques (Txx) implemented in the ZVR can be selected as a calibration method. The keypad M*easure Calibration Standards* can only be operated when the necessary entries have been made.

Window ***Direct Inner Calibration: Txx***
(called up via keypad *Measure Calibration Standards* in the window *Inner Calibration: Define Connector and Cal Method*):
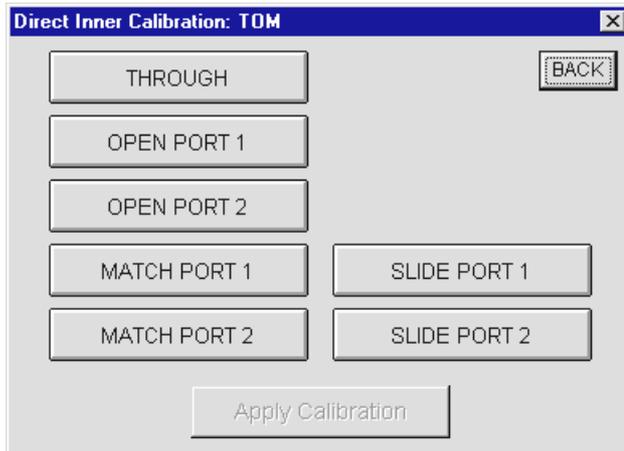
These windows correspond to the calibration measurement menus for 7-term techniques with ZVR operation via the front panel. The softkeys for measuring the standards are simulated by keypads in terms of labeling and functions. By actuating a keypad, the calibration sweep is triggered; when it is finished, the key turns green. All standards can be measured in any order and as often as desired. While the individual standards are measured, a plausibility check is performed. A message window pops up if any of the measurement results appear implausible. The keypad *Apply Calibration* can only be operated when the minimum number of standards have been measured. *Apply Calibration* permits to return to the window *Direct Measurement* after computation of the correction values. A message window appears also if the implicit verification procedure during the calculation of the correction coefficients yields and error or if any of the standards are not defined in the current sweep range. The keypad *Inner Cal* turns green to indicate that the inner calibration has been performed. If required, it can be repeated as often as desired like the measurement of a single standard.

Window ***Direct Outer Calibration: Cal Source***
(called up via keypad *Outer Cal* in the window *Direct Measurement*):

For the outer calibration the same is true as for the inner one. After the inner and outer calibration have been performed, the key *Calculate Transformation Network* in the window *Direct Measurement* can be operated.

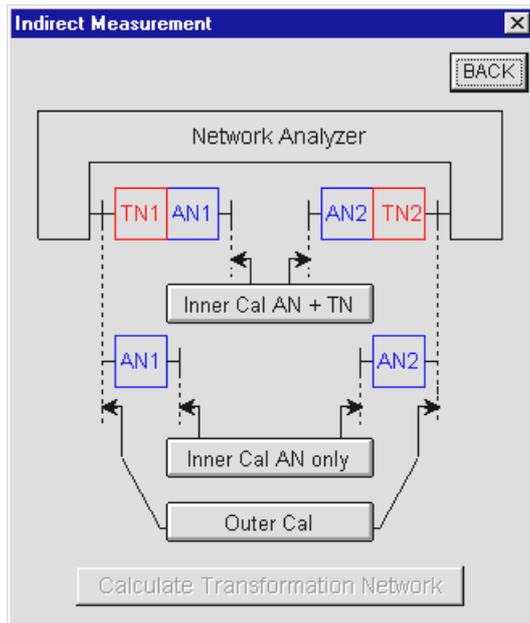Window ***Save Transformation Network***
(called up via keypad *Calculate Transformation Network* in the window *Direct Measurement*):

This window is identical to the one described under *File – Import*. The field *Name* permits to determine the name under which the imported data are stored as virtual network. This name must comply with the DOS convention for file names and has no extension. No differentiation is made between upper-case and lower-case letters. The *Network List* lists all networks stored so far. The field *Comment* permits to enter an optional comment with a length of up to 256 characters. This additional information will then appear in the detailed network list under the command *Embedding*.

After confirmation with *OK*, the difference between inner and outer calibration is formed and stored as transformation network. A bar in the status line shows the progress of the storage procedure. After the storage, the window *Measure Network* appears which permits to return to the window *Direct Measurement* (page 17) via the keypad *Meas Window*. This may be useful if, after storage, you notice that an error has occurred in a calibration and you want to repeat this calibration. The other keypad *Main Menu* permits to return to the main menu, deleting the inner and outer calibration. In this case, the window *Active Calibration* enables you to adopt the outer calibration as the active one. Actually, the outer calibration is often identical with the one in which the network is to be considered in the following step.

Window **Indirect Measurement**
(called up via keypad *Indirect* in the window *Access to Transformation Network*):


In the case of the indirect measurement of a transformation network, two physical networks are given, namely the auxiliary network combined with the transformation network as well as the auxiliary network alone. For example, the combination of auxiliary network and transformation network may be a test fixture with integrated matching circuit, the auxiliary network alone a test fixture without matching circuit. Therefore, as opposed to the direct measurement, two inner calibrations are required. The keypad *Inner Cal AN+TN* starts the calibration with auxiliary and transformation network, the keypad *Inner Cal AN only* starts the calibration with the auxiliary network only. In terms of key functions and test procedure, the indirect measurement corresponds to the direct measurement.

Both for inner and outer calibrations, it is possible to select the currently active one. All other calibrations are thus reset to the "not performed" status, the corresponding keys turn gray.

Embedding

The command ***Embedding*** opens the Embedding window which permits to consider a virtual transformation network in the system error correction data:
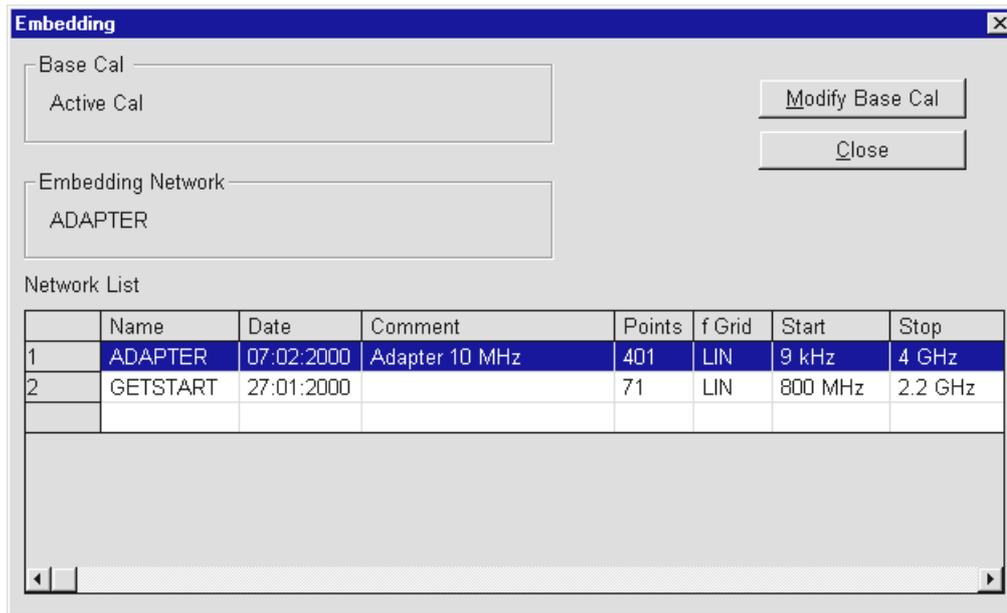
A device under test, which is measured with correction data modified like this, behaves as if it were embedded into the transformation network. The original calibration before the modification is referred to as base calibration. This may be either the currently active calibration or a calibration from the *Cal List* of the *Cal Manager*. Configuration of the base calibration is also performed in the *Cal Manager*. The current base calibration is indicated in the frame *Base Cal*.

The embedding virtual transformation network is selected from the *Network List*. In addition to the name of the network, this list includes a number of other important data, such as date of storage, comment, point grid and frequency range. These data make it easier to find a desired network. If required, the column lines of the *Network List* can be shifted using the cursor, e.g. in order to make a longer comment completely visible. If not all networks can be shown in the list, a scrollbar will appear at the right-hand edge. A network can be selected by clicking on it with the mouse, the respective line being displayed on colored background. The name of the currently selected virtual network is indicated in the frame *Embedding Network*.

Modify Base Cal

The keypad *Modify Base Cal* starts the computation of the modified calibration. A bar in the status line indicates the progress of the computation. After successful termination, a message is output, the modified calibration is activated and the program returns to the main menu level.

The base calibration must have been performed according to a *Txx* technique (7 error terms). Therefore, normalization, one-port calibration or 12-term calibration (TOSM) cannot be used.

The modified calibration features the same point grid as the virtual network. In the computation, an interpolation is made between the sampling points of the base calibration. However, this assumes that the base calibration completely covers the frequency range of the virtual network, i.e. extrapolation beyond the frequency range of the base calibration is not possible.

To ensure correct calculation of the modified correction data, the S-parameters of virtual network and base calibration must be referred to the same impedance. Otherwise, a warning will appear.

The modified correction data are only used in the active display channel unless the channels are coupled. It is of no importance whether the base calibration was recorded with coupled or decoupled channels.

Close

The keypad *Close* closes the window *Embedding* and allows to return to the main menu.

De-Embedding

The result of the command *De-Embedding* is inverse to that of the command *Embedding*. Whereas *Embedding* permits to embed a DUT into a virtual transformation network, *De-Embedding* can be used to virtually remove a physically existing network. This is achieved by considering the inverse virtual network in the system error correction data. Of course, the scattering parameters of the network must be known for this purpose.

For operation and procedure refer to the command *Embedding*.

Cal Manager

The window ***Cal Manager*** provides functions for the management of system error correction data:
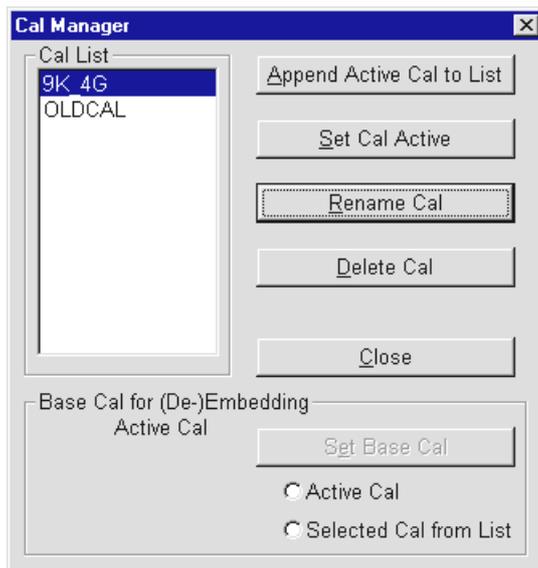
System error correction data can be stored on the hard disk irrespective of the SAVE-RECALL mechanism of the ZVR. The active correction data can be stored under a freely selectable name, conversely, the stored data can be activated again. The files stored are displayed in the *Cal List*. Correction files can be renamed or deleted. The Cal Manager also permits to determine the base calibration to be used for embedding or de-embedding. Possible base calibrations are the active calibration or the one marked in the *Cal List*.

Append Active Cal to List

The function *Append Active Cal to List* adds the active calibration to the *Cal List*. The correction data are transferred, irrespective of whether they are permissible as base calibration for embedding or de-embedding. The name may comprise up to 8 characters. The keypad *Append Active Cal to List* can only be operated if an active calibration is available.

Set Cal Active

The function *Set Cal Active* permits to activate the calibration marked in the *Cal List* by means of the selection bar. This keypad can only be operated if there are entries in the *Cal List*.

Rename Cal

The function *Rename Cal* is used to rename the calibration marked in the *Cal List* by means of the selection bar. The name may comprise up to 8 characters. This keypad can only be operated if there are entries in the *Cal List.*

Delete Cal

The function *Delete Cal* permits to delete the correction file marked in the *Cal List* by means of the selection bar. This keypad can only be operated if there are entries in the *Cal List* .

Close

The keypad *Close* closes the *Cal Manager* and returns to the main menu.

Set Base Cal

The function *Set Base Cal* is used to determine the base calibration, which is modified by the commands *Embedding* and *De-Embedding* in the main menu. It is possible to choose between active calibration (button *Active Cal*) and the calibration marked in the *Cal List* (button *Selected Cal from List*). This selection is to be made before actuating the keypad *Set Base Cal*.

The currently selected base calibration is indicated both at the top left in the frame *Set Base Cal for (De-)Embedding* and in the frame *Base Cal* at the top left in the window *Embedding* or *De-Embedding*.

Info

The command *Info* calls up the program information for Software Option ZVR-K9.

The *OK* button closes this window.

Application Examples

Embedding: Testing SMD Components with a Virtual Matching Network

In the application circuit certain components are embedded into a matching network. For example, high-impedance SAW filters to be integrated into a 50-ohm system must be provided with a transformation circuit. The behavior in the circuit is determined by the composite network consisting of component and transformer only. Therefore, these components are often specified together with the matching network and must therefore also be tested in the matching circuit.

The component test with matching network involves the problem that measurement results of various test fixtures of the same type are comparable only to a limited extent because of the unavoidable tolerances of the matching network. This implies that a relatively high measurement uncertainty has to be assumed, which is to be subtracted from the specified values in the component test and thus results in a poorer yield. Therefore, it would be favorable to use a virtual, tolerance-free matching circuit in the measurement instead of a real one.

This virtual matching circuit can either be calculated with the aid of a CAD program, or a physically existing circuit is measured. The second procedure is to be recommended if there are parasitic effects which are difficult or impossible to account for in a model.

For testing SMD components, a test fixture is required. Necessary matching networks are often integrated into this test fixture. If one wants to change over to virtual matching networks, a test fixture is still to be used for electrical matching of the DUT, however, it is usually less complex and does not contain a physical matching network. In most cases, the matching network itself cannot be measured on its own.

Nevertheless, a virtual transformation network can be determined as the "difference" between the test fixture with matching network and the fixture without matching network (Fig. 6). The series connection of virtual network TN_Δ and test fixture without network TN_U will then be electrically equivalent to the test fixture with network TN_A. One imagines the virtual network to be assigned to the outer ports of the test fixture that are connected to the network analyzer. Thus it can later be considered in the system error correction data F so that the modified correction data F_{mod} are obtained. Due to this definition, the virtual matching network does not necessarily have to feature the same electrical behavior as the real one which is integrated at any place in the test fixture.
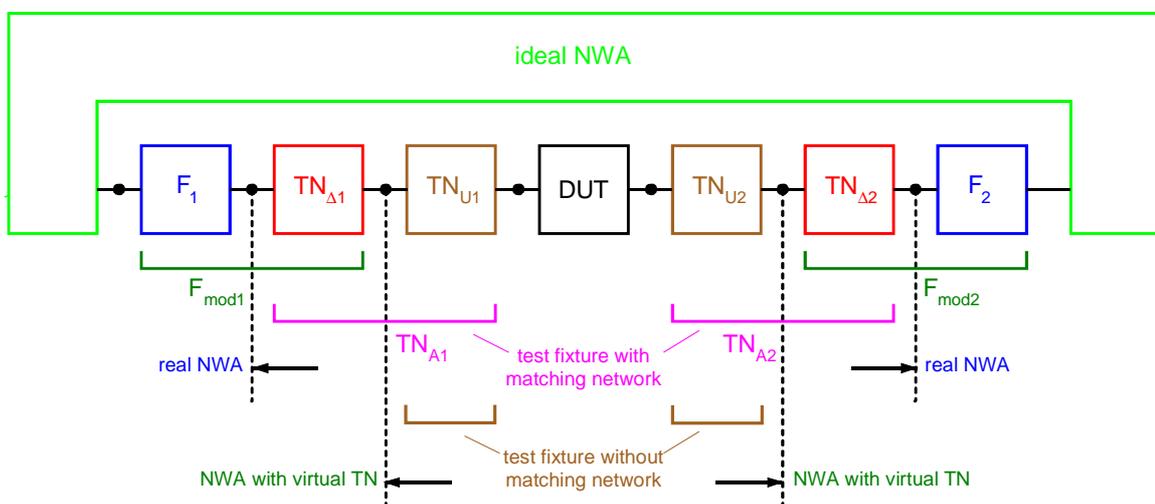

Fig. 6:   Virtual transformation network seen as the "difference" between a test fixture with and a test fixture without matching network

A typical test fixture has coaxial connectors where the test cables of the network analyzer are connected, and contacts for the DUT which are matched to the shape of the case of the component to be measured. For determination of the virtual network the assumption is made that the coaxial connectors at the test fixtures with and without matching network are identical. The virtual network can then be calculated by means of three calibrations.

The command *Measure Network* leads to the window *Access to Transformation Network*, which permits to call up the window *Indirect Measurement* via the keypad *Indirect*. The reference plane of the outer calibration started with *Outer Cal* are the generally coaxial ports of the test fixture to which the network analyzer is connected.

For the two inner calibrations that are performed at the contacts to the DUT, special calibration standards are required. By installing these standards into a case corresponding to the DUT, you can make sure that the field distribution at the test ports is the same for calibration and measurement. Of course, this is only possible if the case can approximately be regarded as matched and loss-free. In the case of non-coaxial test ports, the production of precise standards is particularly difficult. It is therefore recommended to use a self-calibration method such as TRM, TRL or TNA for the inner calibrations, where not all standards have to be known exactly. For TRM, e.g., it is sufficient to use a piece of a transmission line with reference impedance Z_0 and known length, besides two terminations with Z_0. The *REFLECT* standard can be implemented by leaving the contacts open in the case of symmetrical test fixture contacts.

After the calibrations have been performed, the virtual matching network is calculated and stored via the keypad *Calculate Transformation Network*. It can then be embedded in the previously recorded calibration or in a new outer coaxial calibration. If you measure a component in the test fixture without matching network by means of this modified calibration, the same result will be obtained as if you had used the original calibration and the test fixture with matching network.

De-Embedding: Measurement of "Embedded" Components

A further case of application for the Software Option ZVR-K9 is the characterization of embedded components. These are not accessible for a direct measurement, because they are inseparably connected with a transformation network. For example, one might want to measure the scattering parameters of an MMIC, which cannot be removed from its case. Another example is the investigation of the transmission, reflection and crosstalk of a connector for printed circuit boards. To be able to connect this connector to a network analyzer, male and female connector are each soldered into an adapter board with coaxial connections. If the characteristics of the connector alone are to be determined, the adapter boards must be removed computationally.

If the scattering parameters of the transformation network are known, measurement problems like this can be solved with the aid of the de-embedding procedure. If it is not possible to simulate the network with sufficient accuracy using a CAD program, the scattering parameters must be measured. Unlike in the above application example, the command *Measure Network* now permits to select direct access to the network ports. In this case, one calibration must be performed at the inner ports and one at the outer ports of the transformation network. For non-coaxial devices under test, the calibration procedures TRM or TNA are suitable. If the transformation network is an SMD case, special standards are required both for the inner and outer calibration. If reproducible case characteristics can be assumed, it is often useful for the inner calibration to install the standards permanently in the case.

Measuring a Microstrip Transition

In the de-embedding example mentioned above, one part of the measuring task was to determine the embedding transformation network. However, it may even be the measuring task itself to determine and display the S-parameters of a transformation network.

In state-of-the-art microwave circuits, there is a growing tendency towards the exclusive use of planar transmission line structures without coaxial interfaces. It is conceivable, e.g., that several microwave modules on ceramic substrates are combined on a printed epoxy motherboard (PCB) which contains only RF connections and AF circuits to form a single module. The transition from the printed circuit board to the ceramic substrate must be as low-reflection and low-loss as possible.

If the transition is regarded as a transformation network, it can be determined by forming the difference between calibrations at the outer ports (on the PCB) and the inner ports (on the ceramic substrate). The TRM or TNA method should be used for the calibrations. Fig. 7 shows the calibration standards used.
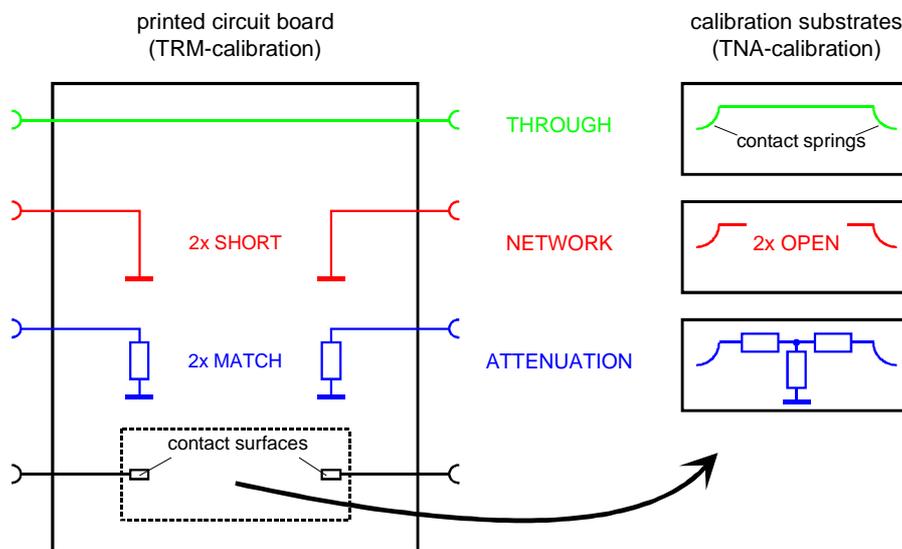
Fig. 7:   Calibration standards for measuring a transition
from printed circuit board to ceramic substrate

The command *Measure Network* permits to determine the S-parameters of the transition and store them as a transformation network. To make them visible, the network can be exported in a CAD file format (e.g. Serenade, Series IV, ADS) and imported by the respective program as a black-box element. Fig. 8 shows the S-parameters of such a transition. Of course, the CAD program also permits to investigate its behavior in a simulated circuit environment or match a transition model to the measured data by optimizing the parameters. If required, the modified model can then be imported again as a virtual network into the Software ZVR-K9.
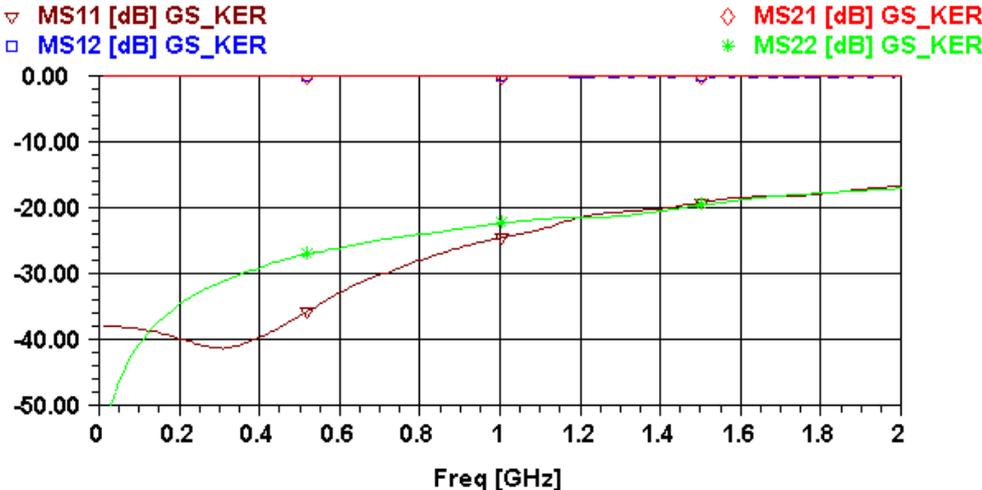
Fig. 8:   S-parameters of a transition from PCB to ceramic substrate

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