In Situ Calibration Utilizing the R&S®ZN-Z3x Inline Calibration Units

Application Note

Products:

R&S®ZN-Z30	R&S®ZVA
R&S®ZN-Z32	R&S®ZNB
R&S®ZN-Z33	R&S®ZNBT

This application note reviews a new calibration subsystem which consists of Inline Calibration Units (ICUs). These ICUs are designed for in situ use, so they are left in place both during the calibration procedure and during the measurement of the Device Under Test (DUT).

This adds versatility, convenience and accuracy to the VNA based measurement system, as it means the calibration can be refreshed at any time without manually disconnecting the DUT from the test system.

Application Note
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1 Overview and Motivation

The most accurate instrument in an engineering lab is the Vector Network Analyzer (VNA). The accuracy is provided by vector error correction algorithms which are built into the firmware of the VNA.

This application note reviews a new calibration subsystem which consists of Inline Calibration Units (ICUs). These ICUs are designed for in situ use, so they are left in place both during the calibration procedure and during the measurement of the Device Under Test (DUT).

This adds versatility, convenience and accuracy to the VNA based measurement system, as it means the calibration can be refreshed at any time without manually disconnecting the DUT from the test system.

Applications that benefit from Inline Calibration Units include:

- Production – Re-calibration can be performed frequently, improving production tolerances and reducing costs, due to speed of operation and the reduced number of connector mating cycles.
- Multi-port – Management and calibration of multi-port applications become less of a burden, since many Inline Calibration Units can be simultaneously supported.
- Thermal Vacuum Chambers (T-VAC) – All R&S ICUs are characterized over temperature, and one model is certified for use in T-VAC. Therefore, the Inline Calibration Units can be placed in the environmental chamber with the DUT, to ensure the most accurate measurements possible.

1.1 Calibration

The VNA needs to be calibrated to provide a vector corrected measurement of the DUT. Selecting a calibration approach is outside the scope of this Application Note, but guidance can be found in the book *Fundamentals of Vector Network Analysis* by Michael Hiebel. [1]

All calibration techniques have several common elements as described in this section.

1.1.1 Step 1: Connection of Precision Standards

In a first step VNA based measurement systems require the temporary connection of several precision standards at the calibration reference planes. The VNA measures the precision standards and compares the measured results to the expected response for each standard. Finally, the VNA uses these results to populate an error model of the measurement system.

The precision standards are commonly one port or two port components such as loads, shorts, opens, airlines, etc. They often have standard coaxial interfaces, such as 3.5 mm, 2.92 mm, 2.4 mm, 1.85 mm or 1 mm connectors. During calibration these components are carefully attached to the coaxial cables at the measurement system's reference plane, and tightened with a torque wrench.

This is a manual process which requires close attention to ensure the correct standard is connected at the proper time in the calibration sequence, as well as to ensure a good interconnection between the coaxial cable and the standard. The standard is connected "finger tight" to ensure it is not cross threaded, and then it is tightened with a torque wrench to provide a consistent and repeatable connection.

For more information regarding various coaxial connector types and how to properly mate and torque the connections, please refer to the application note, “Guidance on Selecting and Handling Coaxial RF Connectors used with Rohde & Schwarz Test Equipment.” [2]

In recent years Automatic Calibration Units (also known as Calibration Units or Auto Cals) have been utilized to make this process easier by allowing the VNA to electronically switch the standards (such as an open, short, match or through) into the appropriate position, eliminating some of the manual process.

1.1.2 Step 2: Measurement of the Device Under Test

In a second step the Precision Calibration Standards or Automatic Calibration Unit are disconnected from the VNA based measurement system, and the DUT is connected at the calibration reference planes.

At this point the VNA based measurement system uses the error model from step one to provide vector corrected measurement results on the DUT.

1.1.3 Limitations of the Two Step Calibration Process

This two-step process is well known in Vector Network Analyzer based measurement systems, but it has several drawbacks.

- Manual connection of the precision standards is an error prone process. The standards often look similar and can be mixed up during the calibration process. If this is not noticed, the result is erroneous measurements of the DUT.

- Regular calibration results in a high number of connections and disconnections of the precision standards to the coaxial cables in the measurement system. Mechanical wear of the standards and the connectors on the cables is inevitable, resulting in gradual degradation in the performance of the measurement system.

- Connection of the standards often requires repositioning and flexing of the coaxial cables, which causes shifts in the insertion characteristics of the cables. In particular, the insertion phase, insertion loss and insertion delay of the cables changes as the cables are repositioned. The calibration algorithms can only correct for constant artifacts, so changes in the cable's insertion characteristics results in errors during the measurement of the DUT.

- The Device Under Test may be located in a thermal chamber or a vacuum chamber, where it is not convenient to access the coaxial reference plane, making the connection of the precision standards impractical.

- Further, this means a portion of the coaxial cables, and test set components such as a splitter or a pre-amplifier are also located in the thermal chamber, resulting in variation of their RF characteristics due to temperature. Any changes that occur after calibration result in additional errors during the measurement of the DUT.

2 Introducing Inline Calibration Units (ICUs)

The R&S®ZN-Z32 and R&S®ZN-Z33 Inline Calibration Units (ICUs) were developed to overcome the limitations described in the previous section.

The concept is to connect an electronically controlled Inline Calibration Unit (ICU) to the VNA based measurement system, and keep it in place during both the calibration of the VNA and during the measurement of the Device Under Test (DUT).

2.1 Characteristics of the Inline Calibration Units (ICUs)

ICUs have the following characteristics:

- To be left in place means that each ICU needs an input port and an output port. The input port is connected to the VNA based measurement system, and the output port is connected to the DUT.

- The calibration reference plane is located at the output port of the ICU. This means the ICU must be left in place after calibration.

- Each measurement port of the VNA based measurement system needs a dedicated ICU.

- The ICU needs to be electronically controlled, similar to the way automatic calibration units are electronically controlled by the VNA during the calibration process. The ICU contains electronically controlled open, short and match precision standards.

- All ICUs are characterized over temperature, allowing their use over the temperature range of +5°C to +40°C.

- There is a model of the ICU available for use in a thermal vacuum chamber. This T-VAC model is characterized over an extended temperature range of -30°C to +80°C, and is built with T-VAC compliant components which will not outgas in a vacuum.
- All CAN bus control cables are `vacuum baked-out in accordance to MSFC-SPEC-684)`

2.2 Description of the ZN-Z32 ICU

Figure One: R&S®ZN-Z32, 10 MHz to 8.5 GHz
(For use over a temperature range of +5°C to +40°C)

R&S®ZN-Z32 covers the frequency range of 10 MHz to 8.5 GHz.

Figure One shows the R&S®ZN-Z32 Inline Calibration Unit. This model has a female SMA connector which interfaces with the VNA measurement system, and a male SMA connector which connects to the DUT.

Electronic control is provided over a CAN bus interface, and the ZN-Z32 has a CAN input and a CAN output connector to allow the CAN bus to be daisy chained from ICU to ICU.

A display shows which VNA port corresponds to this ICU, making it easy to properly connect the ICU to the DUT.

A button illuminated with an LED is used to remotely initiate calibration sweeps, adding convenience during initial setup of the system.

2.3 Description of the ZN-Z33 ICU

Figure Two: R&S®ZN-Z33, 10 MHz to 40 GHz
(For use over a temperature range of +5°C to +40°C)

R&S®ZN-Z33 covers the frequency range of 10 MHz to 40 GHz.

Figure Two shows the R&S®ZN-Z33. This model has a 2.92 mm (female) connector which interfaces with the VNA measurement system, and a 2.92 mm (male) connector which connects to the DUT.

Electronic control is provided over a CAN bus interface, and the ZN-Z33 has a CAN input and a CAN output connector to allow the CAN bus to be daisy chained from ICU to ICU.

A display shows which VNA port corresponds to this ICU, making it easy to connect the ICU to the DUT even if the VNA is not in sight.

A button illuminated with an LED is used to remotely initiate calibration sweeps, adding convenience during initial setup of the system.

Figure Three: R&S®ZN-Z33, 10 MHz to 40 GHz
(For use in a vacuum and over a temperature range of -30°C to +80°C)

Figure Three shows the T-VAC R&S®ZN-Z33, which covers the frequency range of 10 MHz to 40 GHz. This model does not have a display or LED illuminated button.

This model has a 2.92 mm (female) connector which interfaces with the VNA measurement system, and a 2.92 mm (male) connector which connects to the DUT.

Electronic control is provided over a CAN bus interface, and the ZN-Z33 has a CAN input and a CAN output connector to allow the CAN bus to be daisy chained from ICU to ICU.

2.4 Description of the ZN-Z30 CAN Bus Control Unit

Figure Four: R&S®ZN-Z30 CAN bus control unit, front and rear.

The ZN-Z30 CAN bus Control Unit provides power and communication to the Inline Calibration Units. There are two CAN bus connectors on the front of the Control Unit, Each CAN bus supports up to 24 ICUs, thus, up to 48 ICUs can be supported by each controller. A status display on the front panel shows details such as how many ICUs are detected on each CAN bus, the IP Address of the Controller, and any error messages.

The back of the Controller has an AC Power switch, an SD card slot, a USB port and a LAN port. The USB port is only used for service operations. The LAN port is used to send commands to the control unit, which in turn controls the ICUs.

Both ZN-Z32 and ZN-Z33 ICUs can be placed on the same CAN bus and controlled with one ZN-Z30 control unit.

Several ZN-Z30 controllers can be connected to the same LAN network, allowing control of a virtually unlimited number of ICUs

2.4.1 Control of the ICUs over the CAN bus

The CAN busses are used to control the ICUs which are located at the end of the VNA cables. The ICUs are connected serially, using the input and output CAN bus connectors to create a daisy chain from the controller to each module on the bus.

The controller automatically detects how many ICUs are connected to each CAN bus when it is first turned on.

Commands are sent over this bus to perform functions such as reading the ICU serial number, selecting the calibration standard within the ICU, reading the embedded temperature sensor of the ICU or for transfer of the characterization data from the ICU to the controller.

Please note: The CAN bus system does not have hot-plug functionality. The ZN-Z32 and ZN-Z33 ICUs can be connected and disconnected (without damage) while the controller is turned on, but the controller will not be aware of this activity. The controller needs to be power cycled off and then back on in order to detect which ICUs are connected to each CAN bus.

2.4.2 Characterization Data of the ICUs

The individualized characterization data of the open, short, and match standards are stored inside each ZN-Z32 or ZN-Z33. These standards are characterized over temperature when the ICUs are manufactured. At some point this data needs to be transferred to the VNA for use during the calibration process.

Upon detection of the ICUs that are connected to each bus, the controller requests a transfer of the characterization data from each ICU using the CAN bus. A copy of this data is stored locally in the ZN-Z30 controller. The data is stored on a removable SD card to comply with use in secure labs, providing control of the movement of data in or out of the secure lab. The SD card is accessed via a slot on the rear panel of the ZN-Z30. This local copy the characterization data is utilized to speed up calibration since it can subsequently be transferred over the high speed LAN connection to the VNA.

It can take several minutes to complete the initial data transfer from the ICUs to the ZN-Z30 controller, depending on how many ICUs are connected to each CAN bus and the overall physical length of the CAN bus. Storing a local copy of this data in the ZN-Z30 controller means subsequent power off and on the controller results in immediate recognition of the ICUs, with no need to repeat the data transfer. Hence calibration of the system can start immediately.

2.4.3 Temperature Sensing within the ICUs

The ZN-Z32 and ZN-Z33 incorporate temperature sensors, allowing accurate tracking of the internal temperature of the calibration standards. The units are factory calibrated over temperature and each contains temperature dependent characterization data. During the calibration process, this data is utilized to offset and compensate for the effects of temperature drift. Highly accurate measurements are achieved even when subjected to large variations in the environmental temperature. Temperature compensation is only used during calibration and is not active when making measurements.

The user can control whether or not the temperature of the ICUs is taken into account during calibration.

2.5 Inline Calibration Tool (Software)

The ZN-Z30 CAN bus Control unit and the connected ZN-Z32 or ZN-Z33 ICUs are controlled with a software program (ZN-Z3ASW) called the Inline Calibration Tool. This software is provided free of charge with the ZN-Z30, and is available from the Rohde&Schwarz web site.

The software directs the calibration process, controlling both the Vector Network Analyzer and the ZN-Z30 Control Unit with its connected ICUs. The complete calibration process is accomplished within the Inline Calibration Tool.

This Inline Calibration Tool can also be controlled remotely using SCPI commands. This allows integration and control of the Inline Calibration Units within a larger automated test program. For more details on this topic refer to the Operating Manual [3].

The following requirements apply to the Inline Calibration tool:

- Supported operating systems: Windows 7, Windows 8 or Windows 10.
- It can be installed on a PC, or on a Rohde&Schwarz ZVA, ZVT, ZNB, ZNBT, ZNC or ZND vector network analyzer.
- The software installer includes an R&S VISA implementation for remote control of the VNA and the ZN-Z30 controller.
- If installed on a PC, the software connects to the VNA and the ZN-Z30 controller through the LAN connector on a local network. This connection takes place through a LAN switch or router.
- If installed on the VNA, then the software controls the VNA though a local host connection, and only requires a LAN connection from the VNA to the ZN-Z30 through the switch or router.
- IP addresses can be assigned automatically or with manual entry in the software.

2.6 The Complete Solution

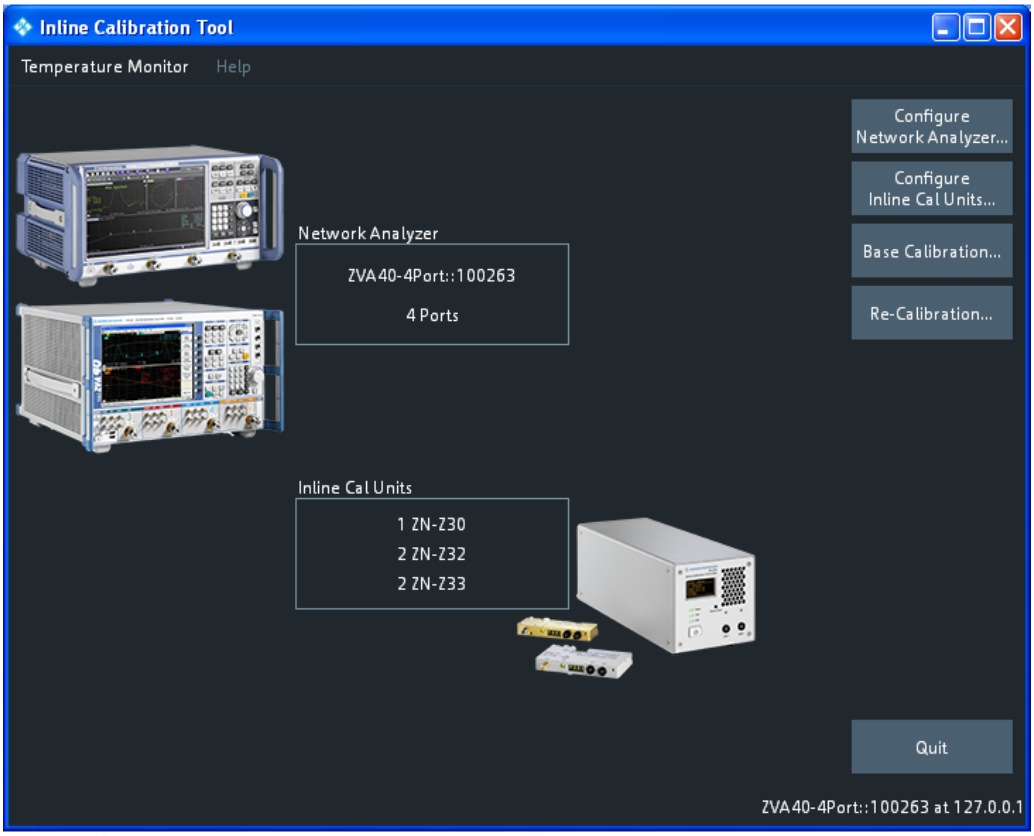

Figure Five: A complete solution consists of a VNA with a corresponding ICU connected to each VNA port. The Controller is connected to the VNA with a LAN cable, and to each ICU with a CAN bus cable. The system is controlled by the Inline Calibration Tool (Software), whose User Interface is shown at the top.

3 Exemplary Use Case

This section describes a two port measurement of a filter using the ICUs to perform the initial base calibration, followed by a recalibration. The process will be described step by step.

3.1 Interconnection of the VNA, the Controller, and optional PC

3.1.1 First Scenario, Utilizing a VNA and Controller

In this scenario the Inline Calibration Tool is installed directly on the VNA. There are several options for making the LAN connections and assigning IP addresses.

Option One uses a router with DHCP capabilities.

1. Connect the VNA LAN port to a router.
2. Configure the VNA LAN properties for automatic IP address assignment.
3. Connect the Controller LAN port to the same router
4. Configure the Controller LAN properties for automatic IP address assignment.

After making the LAN connections and power up of the items, the IP addresses will be automatically assigned.

Option Two uses a router but without DHCP.

1. Configure the VNA for a static IP address, for example 192.168.1.30, with a subnet of 255.255.255.0.
2. Configure the Controller for as static IP address on the same subnet, for example 192.168.1.2, with a subnet of 255.255.255.0.
3. Connect the VNA and the Controller to the router

Option Three uses a direct LAN connection between the VNA and Controller

1. Configure the VNA for a static IP address, for example 192.168.1.30, with a subnet of 255.255.255.0.
2. Configure the Controller for as static IP address on the same subnet, for example 192.168.1.2, with a subnet of 255.255.255.0.
3. Connect the VNA and the Controller LAN ports with a crossover LAN cable.

3.1.2 Second Scenario, Utilizing a VNA, Controller and a PC

In this scenario a PC is added to the system. This is often done to provide remote control of the system with an automated test. Since there are now three items that need to be connected, you must use a router with either DHCP assignment of IP addresses, or with static IP addresses. (Option One or Option Two in the previous section.)

In this scenario the Inline Calibration Tool can be installed on either the VNA or the PC.

3.1.3 Additional Tips Regarding LAN Connections

- To configure the IP address of a PC or the VNA, open the Microsoft Windows control panel, and select the Network and Sharing Center, followed by the Change Adaptor Settings option.

- By default, the controller is configured for DHCP assignment of IP addresses. This is a convenient approach for most applications, especially since the IP address of the controller can be visually read from the front panel display of the controller. But in some cases it is preferable to configure a controller with a fixed or static IP address. The control of this setting is not presently implemented in the Inline Calibration Tool software, but is available in the service software. If this capability is required, please contact your local R&S representative for support.

- To test LAN connections, it is very common to open a command prompt on either the PC or the VNA, by selecting the Start Icon, and typing in “cmd” to open a command prompt window. From this command prompt you can “ping” the other instruments to see if there is a valid LAN connection. To test a connection from the VNA to a controller, with the controller at IP address 192.168.1.40:

  Type “ping 192.168.1.40” into the window with the command prompt.

  A valid connection will result in a reported round trip time. If you get a timeout response, then the two instruments are not able to communicate over the LAN connection.

- An alternative to a router with DHCP is a software program called, “DHCP Server for Windows.” This can be installed on the VNA or on the PC. Further details can be found by following the link in reference [5].

3.2 Initial Setup of the Hardware

An R&S®ZVA-40 VNA is used in this example. It is configured from a preset with the following settings

Start Frequency:	2.8 GHz
Stop Frequency:	3.5 GHz
Point Spacing:	10 MHz
IFBW:	1 kHz

Traces that measure input return loss, output return loss and insertion loss are displayed in three diagrams.

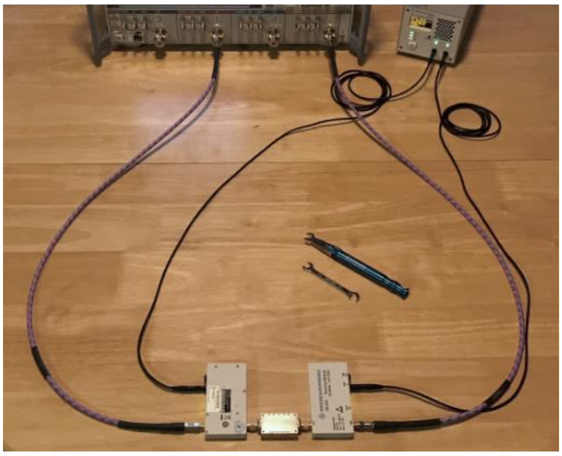

Figure Six: A setup showing the VNA, Controller, two ICUs and a DUT all connected. This setup supports re-calibration and measurement of the DUT without any reconnection of the RF cables.

Two coaxial cables are connected from Ports 1 and 2 of the ZVA to the inputs of two Inline Calibration Units (ICUs). The ICUs are also connected to the controller with two CAN bus cables. Finally, an Ethernet cable is connected between the VNA and controller.

3.3 Configuring the Software

The software can be installed on the VNA, or it can be installed on an external computer that will be remotely controlling the instruments. Operation of the software is identical in both cases.

In this example the software is installed on the R&S ZVA40.

3.3.1 Connect to the VNA

This is the configuration screen that is presented when the software is launched for the first time.

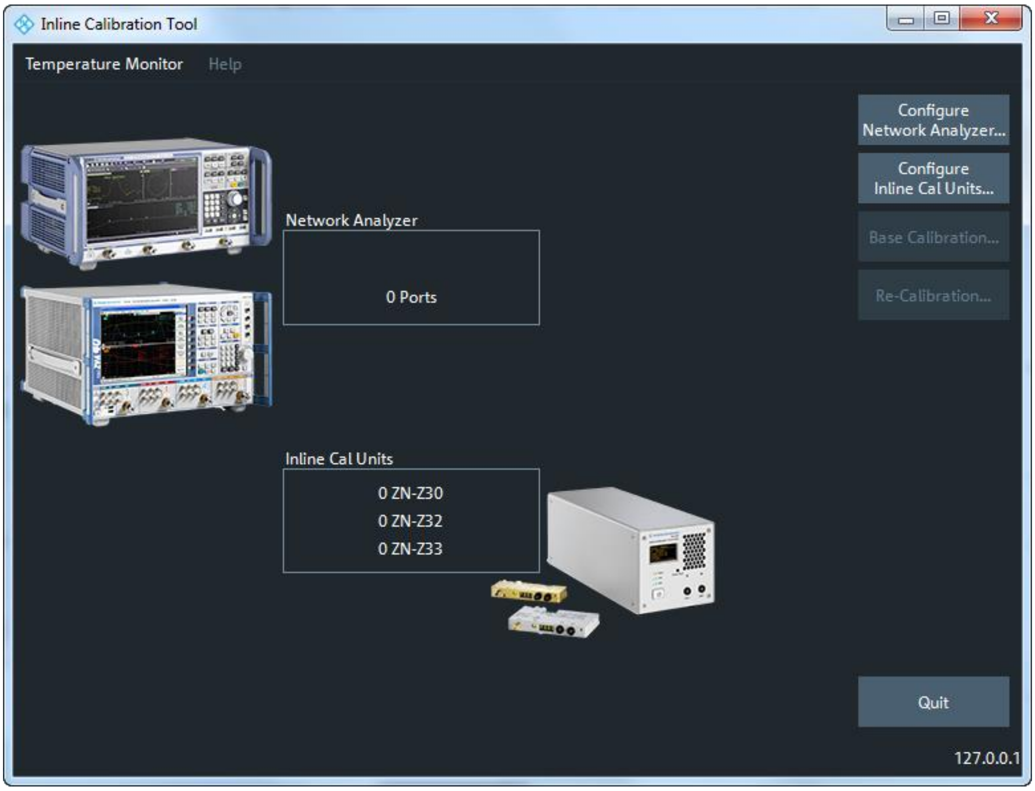

Figure Seven: The initial screen of the Inline Calibration Tool.

First the software needs to be connected to the VNA by pressing the "Configure Network Analyzer…" button.

On this screen the user selects either a GPIB or LAN connection for control of the Network Analyzer.

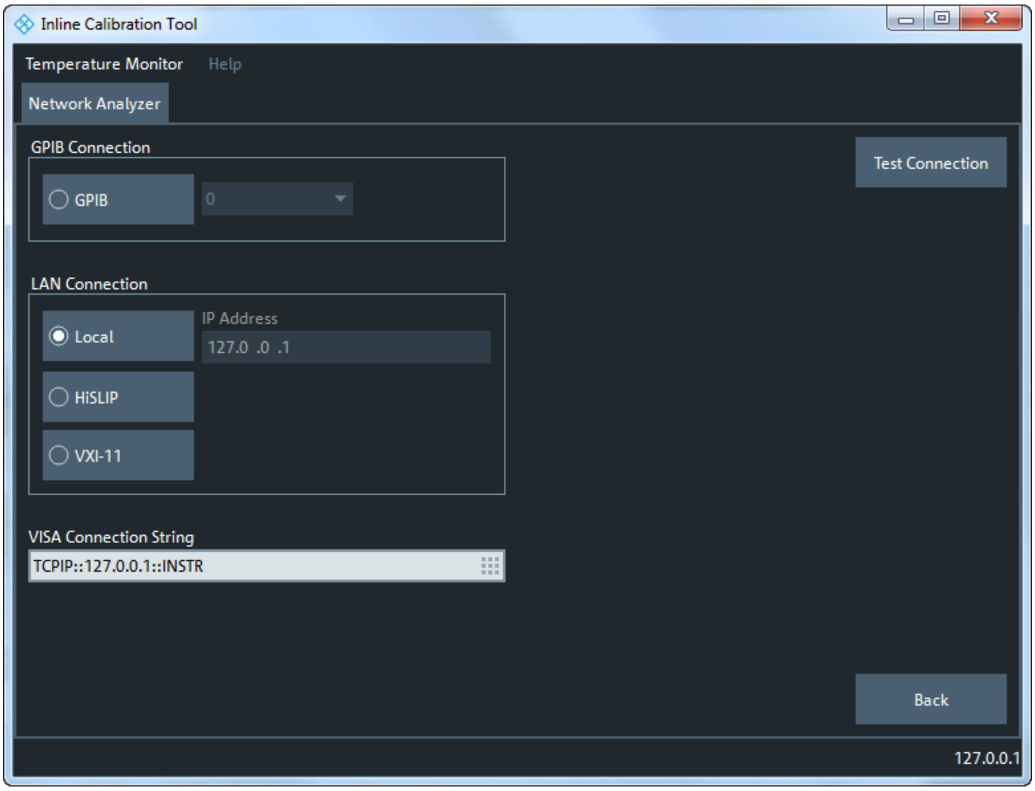

Figure Eight. Configuring the connection of the software to the VNA.

If a GPIB connection is selected, then the GPIB address of the VNA needs to be set in the adjacent entry box. For example, shown here is a GPIB connection with the VNA at GPIB address 22.

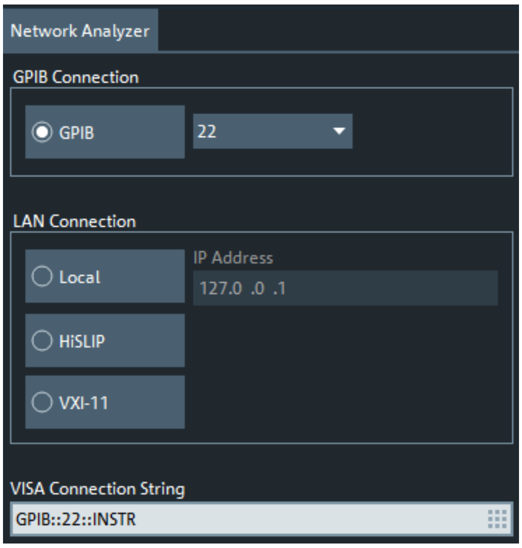

Figure Nine. Settings for a GPIB connection to the VNA.

Alternatively, if a LAN connection is selected, there are three possibilities: Local, HiSLIP and VXI-11. Local is selected when the software has been installed directly on the VNA. In this case the "local host" IP address is automatically entered as 127.0.0.1.

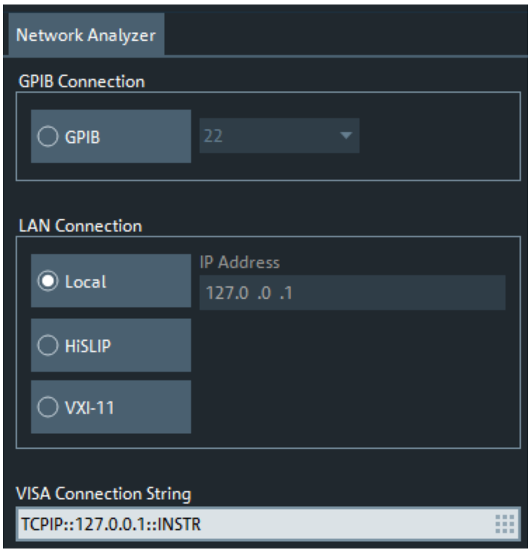

Figure Ten. Settings for control of the VNA when the software is installed directly on the VNA.

If the software is installed on an external computer using the LAN Connection for control, then either HiSLIP or VXI-11 has to be selected. HiSLIP is a newer interface that offers higher speed transmissions. But it may not be supported on older platforms.

VXI-11 is an older protocol which is also a little slower, but VXI-11 is supported on virtually every PC platform.

This application does not send very many commands over the GPIB or LAN interface, so speed of the interface is not a factor.

To select either HiSLIP or VXI-11 control, click the radial button and enter the IP Address of the VNA in the adjacent box. Shown below is a VXI-11 connection to a VNA at IP address 192.168.1.30.

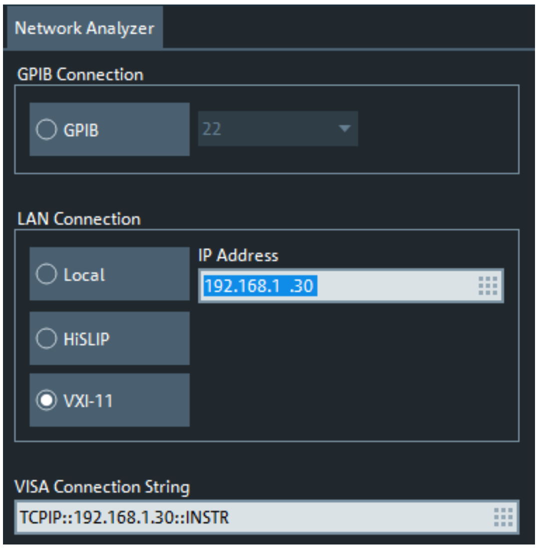

Figure Eleven. Settings for the control the VNA from a remote PC.

After setting the connection parameters, press the Test Connection button in the upper right hand corner to verify everything is working. A confirmation or error message will be displayed in the bottom of the window providing the results of the test.

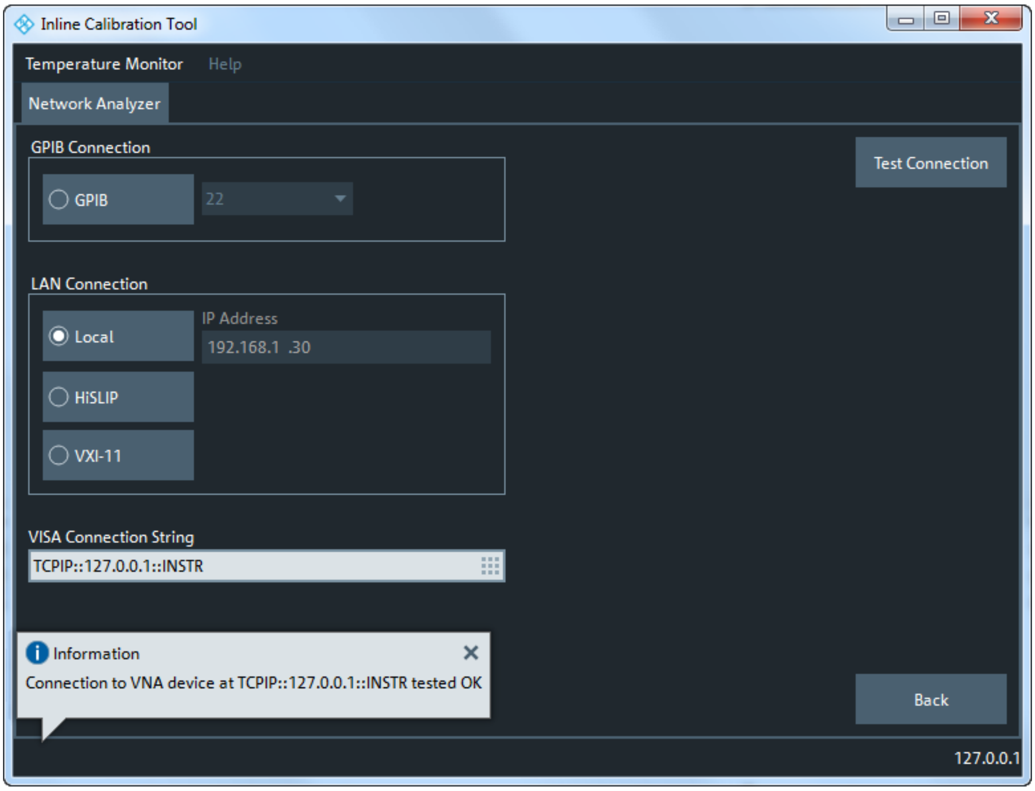

Figure Twelve. Successful Test of the Connection from the software to the VNA.

Complete the VNA Configuration process by pressing the Back button to return to the initial screen. If the VNA connection was successful, then the display is updated with the model number of the VNA, and how many ports it has.

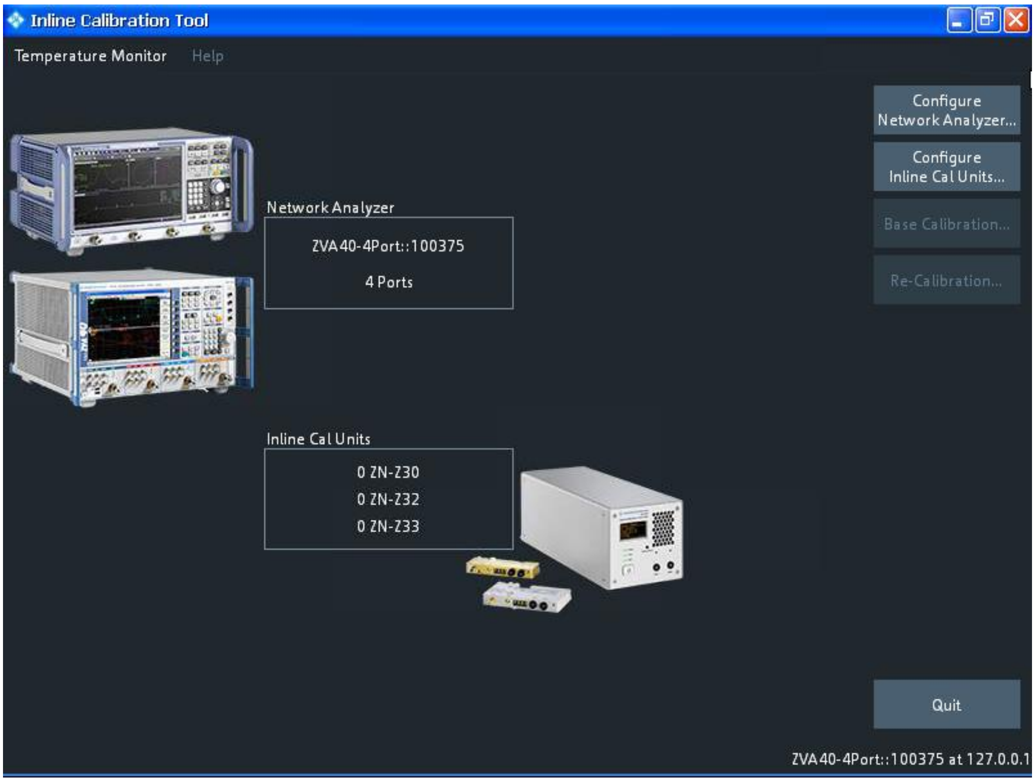

Figure Thirteen. Summary display showing the status of the VNA Connection.

For additional information or for troubleshooting the connection of the software to the VNA, please refer to the more detailed description in the Operating Manual [3].

3.3.2 Connect to the ICU controller

The Inline Calibration Tool supports multiple ICU controllers, and each ICU controller supports as many as 48 ICUs.

Press “Configure Inline Cal Units…” to connect to the first ICU controller. Initial entry into this window returns a blank list. Press the “New” button to configure the first ICU controller.

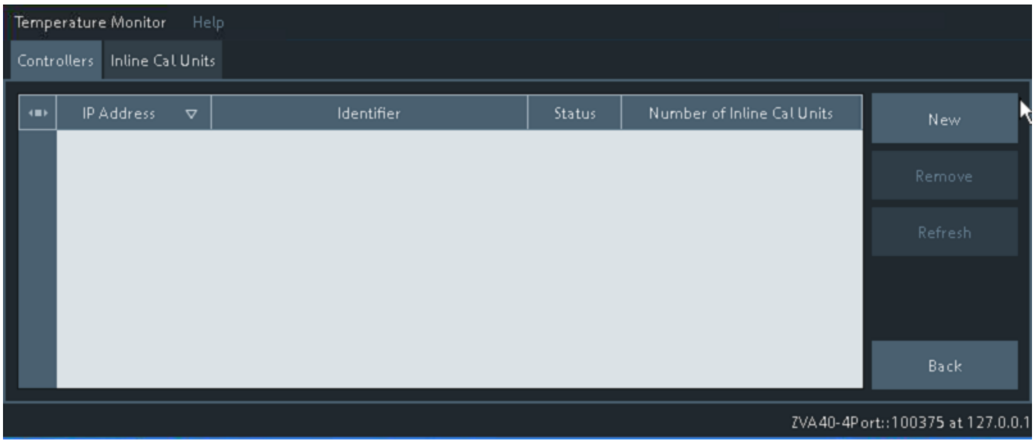

Figure Fourteen. Window for configuring the connection to the ZN-Z30 Controller.

Enter the IP address of the controller in the first box and press enter. The software will connect to the specified controller. The IP address of each controller is shown on the front panel display of the controller.

Figure Fifteen. Front panel of the ZN-Z30 controller showing the IP address.

The software will remember previously configured controllers. Upon returning to this screen the “Refresh” key is used to test or re-establish communication with previously configured controllers.

The window below shows a connection to one controller with two ICUs.

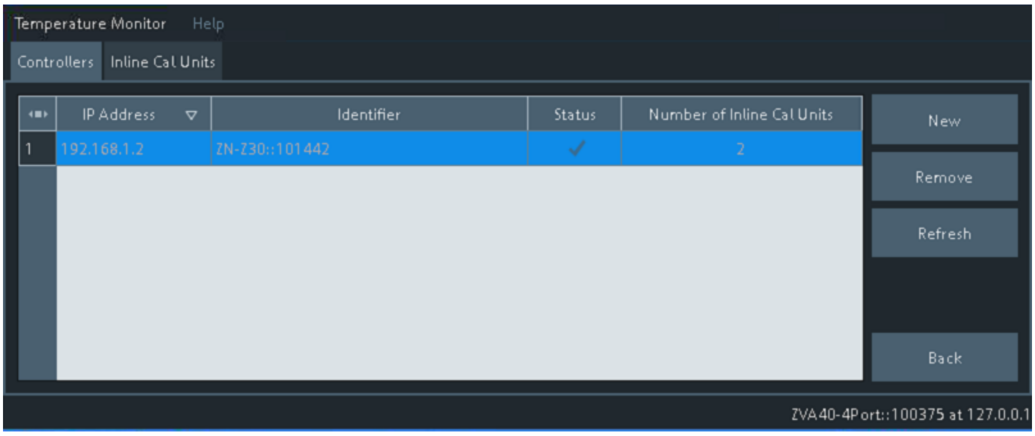

Figure Sixteen. Status window after connecting the ZN-Z30 controller.

A second tab in this window provides a summary table showing all the connected ICUs. Select the “Inline Cal Units” tab to display this table.

As soon as the software has connected to a controller, it starts the process of populating the “Inline Cal Units” tab with the ZN-Z32 and ZN-Z33 ICUs that are connected to that controller’s CAN buses.

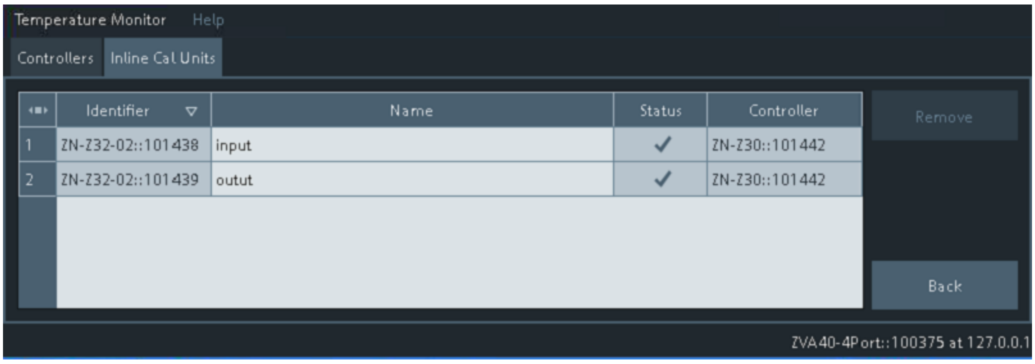

Figure Seventeen. Status window showing the ICUs that are detected by the ZN-Z30 controller.

In this table, aliases or names can be assigned to each ICU. For example, they can be named *Port 1* or *Port 2*, to align with the VNA ports. Or they can be named *DUT input* and *DUT output*, to align with the DUT. Naming the ICUs is optional, and is provided only for the user’s convenience.

Once the Controllers are configured and the ICUs have been detected, press the “Back” button to return to the main window.

If successful, a summary of both the connected VNA and the connected Controllers will be presented, and the “Base Calibration” button will now be active.

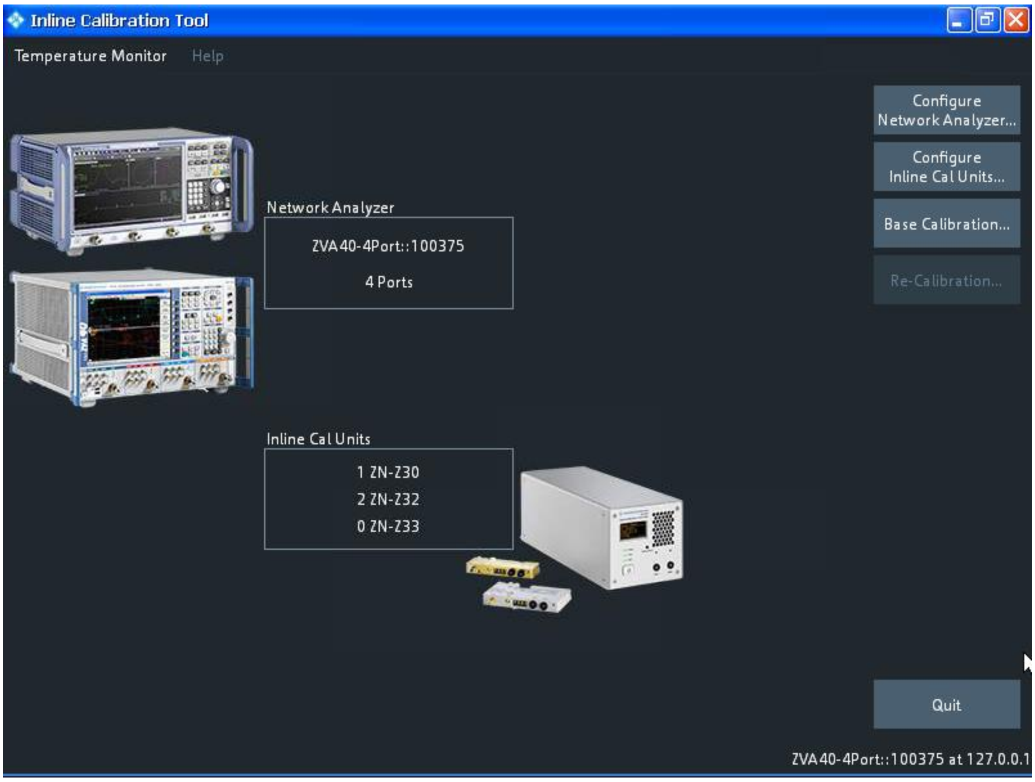

Figure Eighteen. Summary display showing status of the VNA and ZN-Z30 controller.

3.4 Base Calibration (Including Through Paths)

The “Base Calibration” button becomes active upon successful configuration of the VNA and ICUs. The base calibration or initial calibration utilizes the unknown through, open, short and match (UOSM) calibration technique. The open, short and match standards are internal to the Inline Calibration Units that are connected to each port.

The through connection needs to be provided externally as a connection between the port pairs that are being calibrated. This is generally a high quality adaptor with the appropriate connectors, such as a 2.92 mm female to female adaptor from an R&S®ZV-Z292 calibration kit.

The base calibration is a full N port calibration of the VNA.

Pressing the “Base Calibration” button reveals the following window:

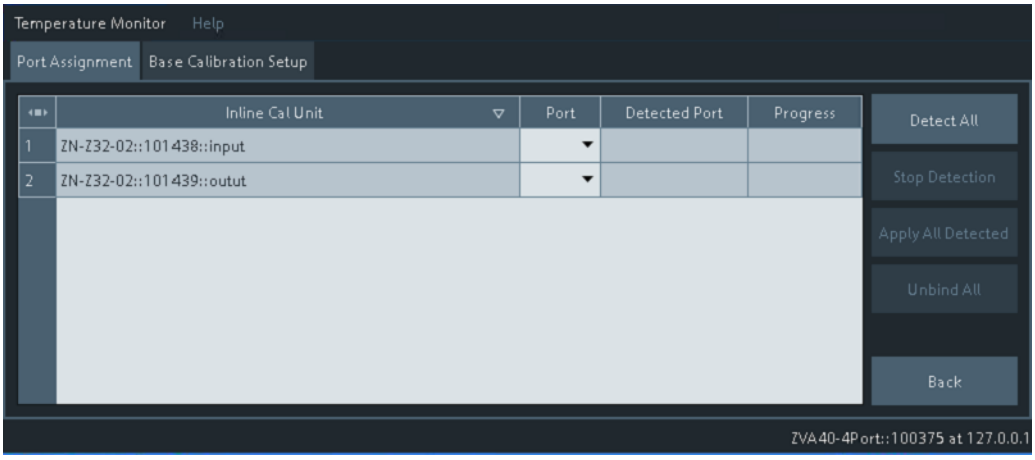

Figure Nineteen. Display of the port assignments for the initial or base calibration.

The assignments between the Inline Calibration Units (ICUs) and the VNA test ports are made in this window. Auto Detection is possible by pressing the "Detect All" button.

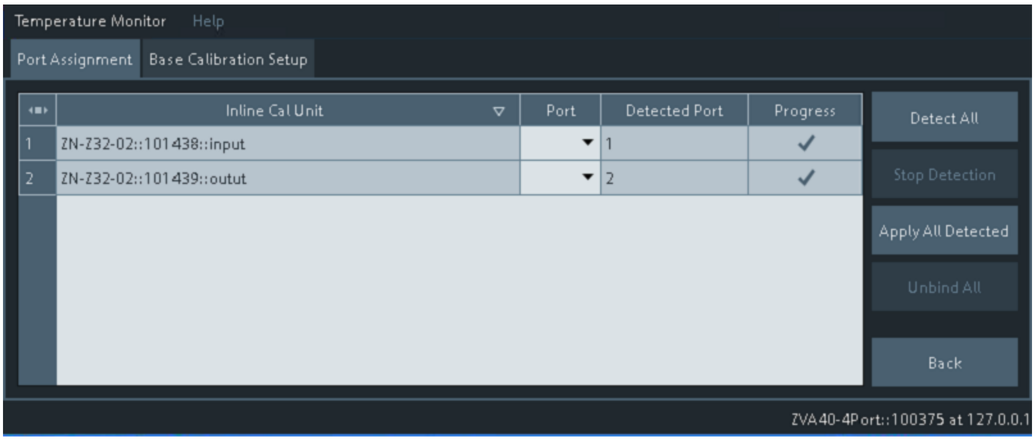

Figure Twenty. Port assignment window after Detect All operation.

"Detect All" fills in the Detected Port column, which is the port number of the VNA that is connected to the corresponding ICU. To accept this assignment, press the "Apply All Detected" button, which fills in the Port column.

The ports can also be assigned manually by editing the entries in the Port column.

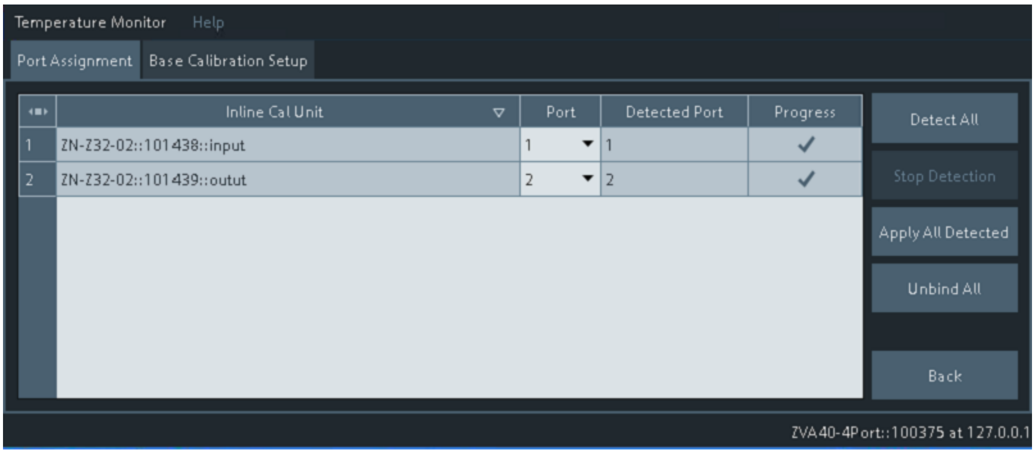

Figure Twenty-One. Port Assignment window after Apply All Detected operation.

Start the base calibration by selecting the "Base Calibration Setup" tab. This reveals selectable calibration parameters.

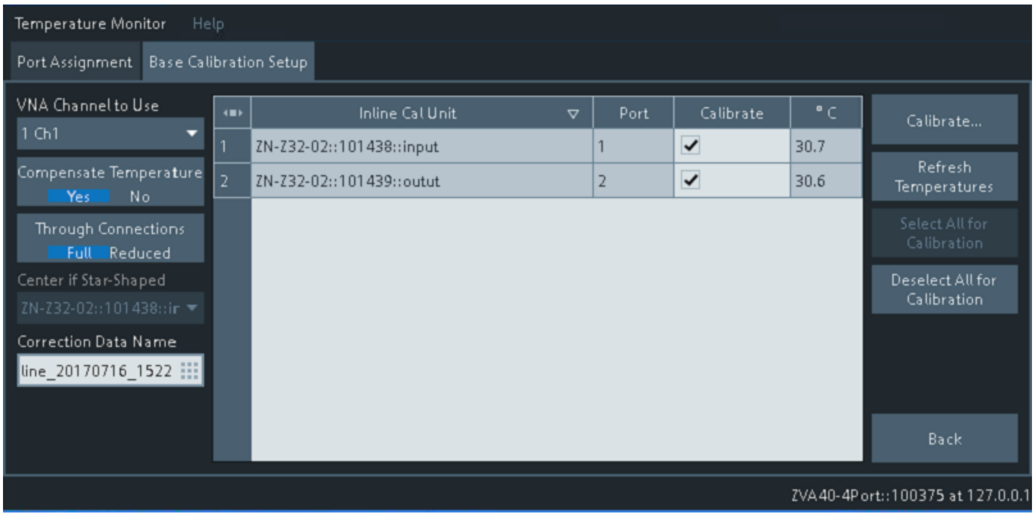

Figure Twenty-Two. Base Calibration Setup window.

Here the user can control a number of factors

- Which VNA channel to calibrate
- Compensate for the temperature of the ICU (creates temperature dependent calibration kits from the ICU characterization data)
- Use all through paths during calibration or use a reduced set of through paths.
- Name the calibration file which will be stored in the Cal Manager
- Select which VNA ports will be calibrated

Make the appropriate choices, and the press the "Calibrate…" button.

In this example a two port calibration will be performed between ports 1 and 2.

The dialog displays one calibration step, which requires a through connection between the ICUs connected to ports 1 and 2 in order to complete the base calibration.

For each calibration step the software flashes the LEDs of the two ICUs that need to be connected to each other. Find the two ICUs with flashing LEDs, connect them with a through, and then press the LED button on each ICU to initiate the sweep. Note: LED buttons are not available on the ZN-Z33 T-VAC model.

Alternatively, the calibration of each port pair can be triggered by pushing the yellow “oo” button in the “Progress” column. (See Figure Twenty-Three.)

Status is displayed at the bottom of the window during the calibration.

At the end of the calibration step a checkmark is placed on the line indicating that step has been completed. Press the “Apply Calibration” to finish the process, and finally close the calibration windows by pressing the” Back” button several times.

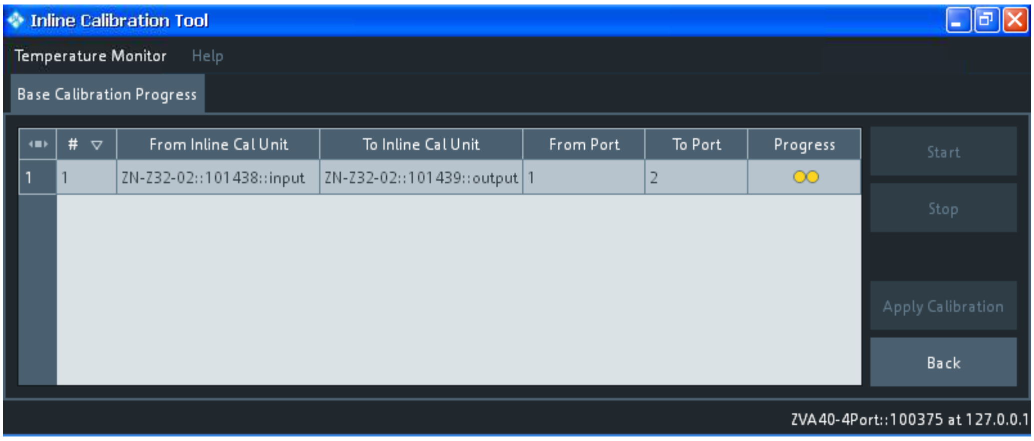

Figure Twenty-Three. Progress window during the Base Calibration

Now that the base calibration has been completed, the “Re-Calibration” button becomes active. Re-Calibration will be covered in the next sections.

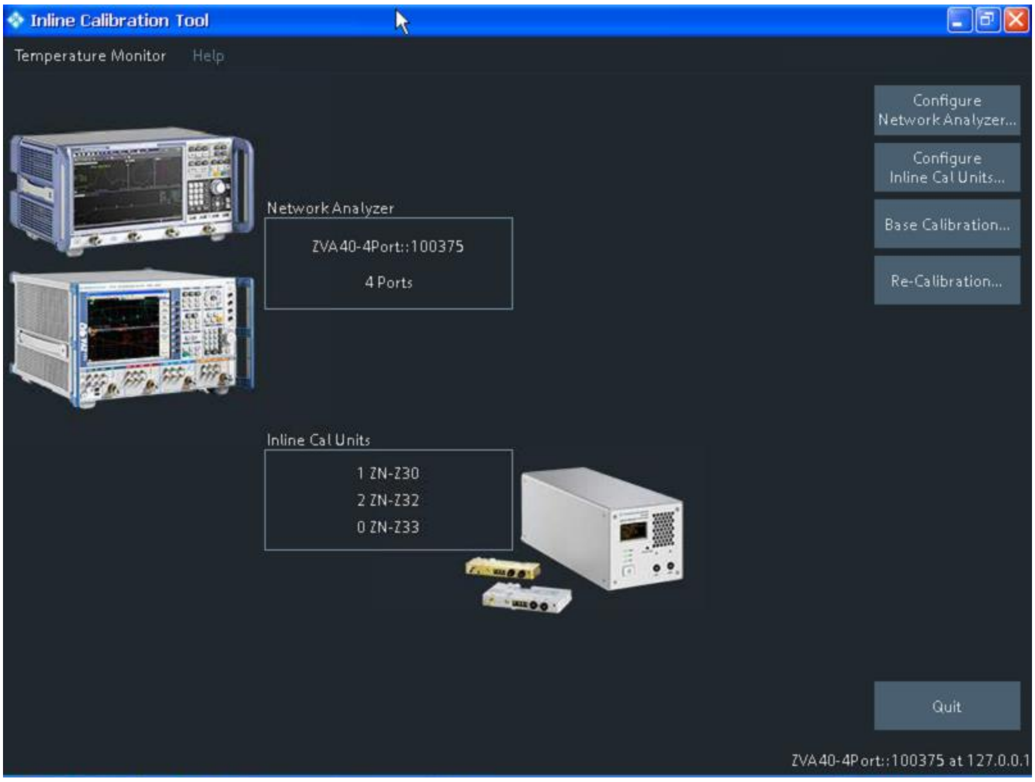

Figure Twenty-Four. The main window after Base Calibration.
Note the Re-Calibration button is now available.

3.5 Initial Measurement of the DUT

After the base calibration, the DUT is connected between the ICUs, and the initial measurements are performed. Up to now the process is similar to using an automatic calibration unit, and the VNA is used to make vector corrected measurements in the usual way.

Below the characteristics of a two port band pass filter are displayed.

Figure Twenty-Five. Connection of the DUT between the two ICUs.
The output connectors of the ICUs are the location of the calibration reference plane.

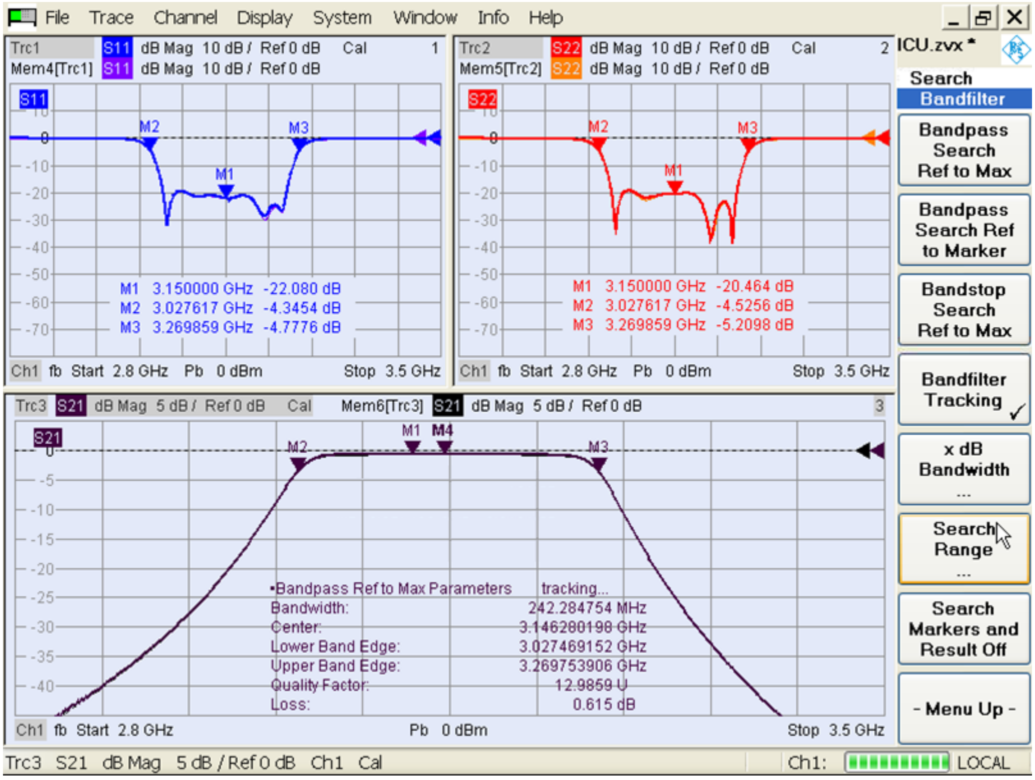

Figure Twenty-Six. Initial measurement results of the 2 port filter immediately after calibration. The measurement results have been saved into the memory traces.

3.6 In Situ Re-Calibration with DUT in place

This section demonstrates the in situ recalibration offered by the Inline Calibration Units. Recalibration can be invoked at any time to update the error model, accounting for a change in temperature or a repositioning of the cables. Since the ICUs are always in place at the end of the VNA cables, the recalibration process simply involves a few key presses (or the sending of a few SCPI commands).

3.6.1 Re-Calibrate to Compensate for Thermal Drift

The plots below show the measurement results of the DUT immediately after the base calibration (as memory traces) and again after 24 hours have passed.

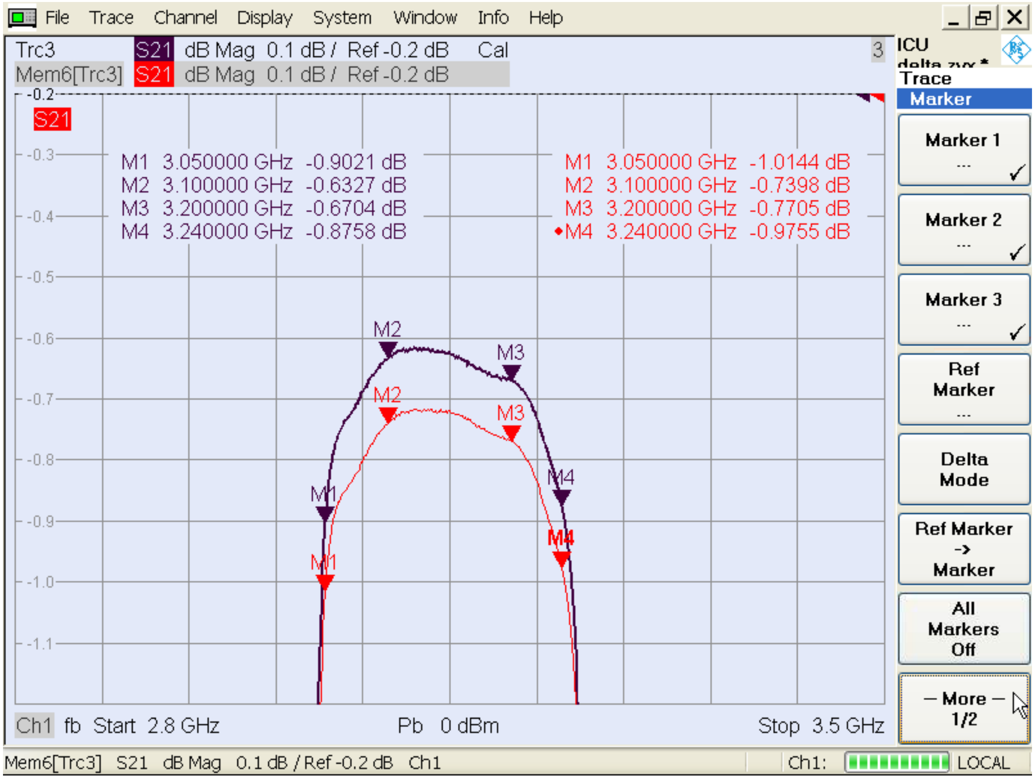

Figure Twenty-Seven. Measurement results of the two port filter 24 hours later.
The memory trace (red) shows the initial measurement result.

It is a subtle change in the measured results, approximately 0.1 dB, but in some applications this amount of change may not be acceptable.

Here in situ re-calibration is utilized to correct for this drift with a press of button. Returning to the Inline Calibration Tool the “Re-Calibration…” button is now available. Pressing this button initiates, the re-calibration. No mechanical user intervention is needed, as the process is completely automated. The re-calibration is performed while the DUT is connected to the ICUs.

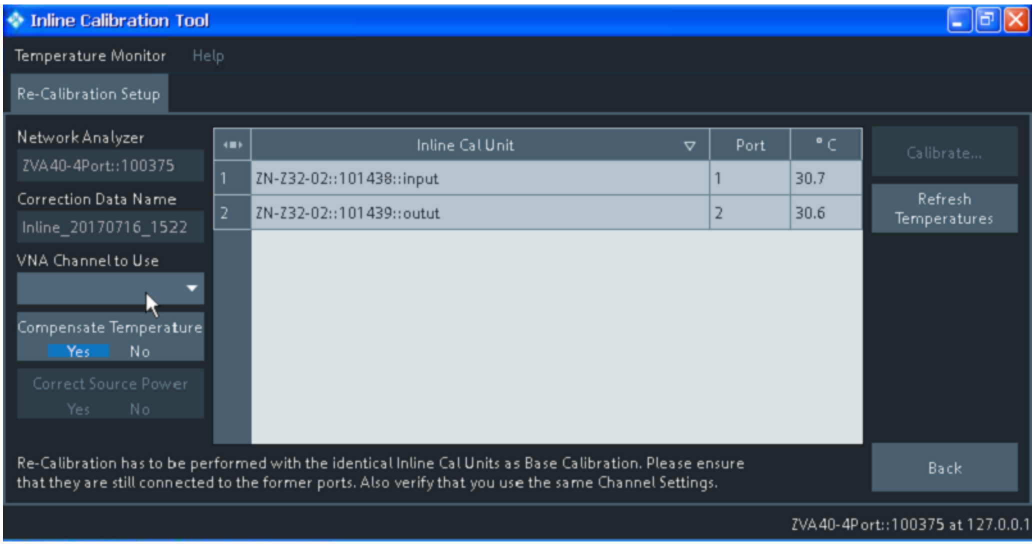

Figure Twenty-Eight. The Re-Calibration Setup window.

Select the Channel to be calibrated and select if the calibration kit should be updated based on the current temperature of the ICU. Then press the “Calibrate…” button.

A second window is displayed listing the ICUs that will go through the re-calibration process. Select “Start All” to initialize the re-calibration.

Status is displayed at the bottom of the window.

Press “Start All” to initiate the re-calibration.

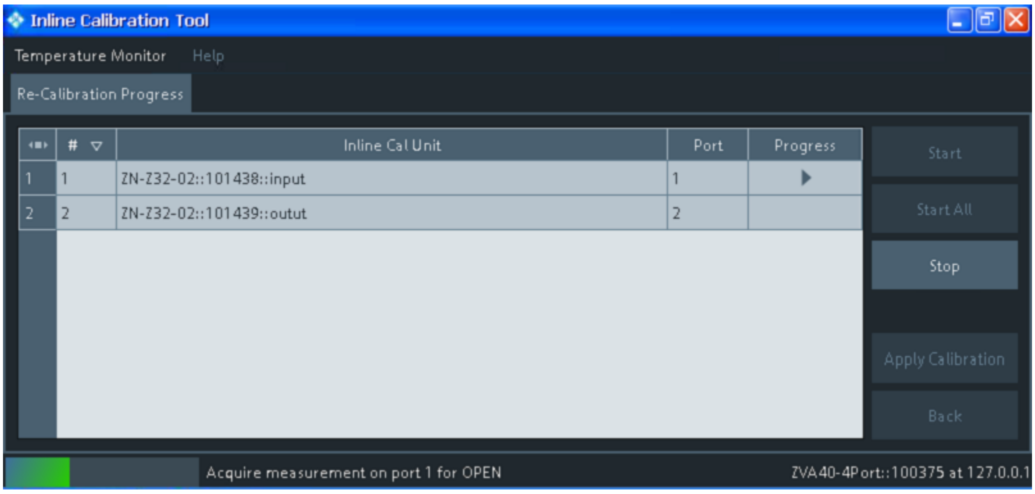

Figure Twenty-Nine. This window shows progress during the recalibration step.

Once completed, “Apply Calibration” and then press the "Back" key several times to complete the re-calibration process.

Re-calibration shifts the measurement results back toward the original data. The delta between the original measurement and the re-calibration measurement is ~ 0.03 dB, compared to 0.10 dB prior to re-calibration.

These are small numbers, as can be expected from a precision VNA based measurement system, but the improvement in performance is achieved with minimal effort and no user intervention.

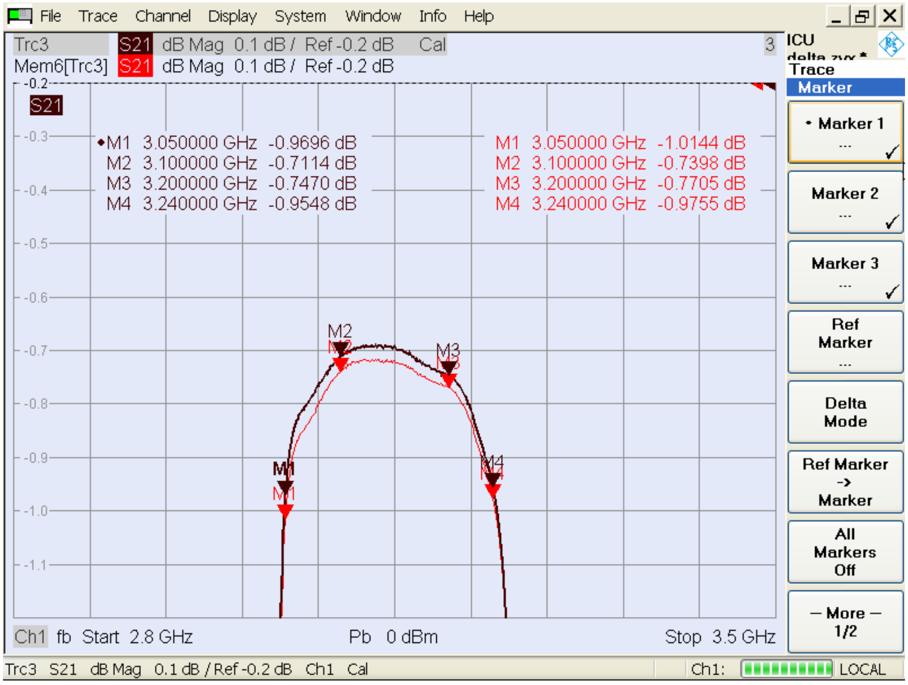

Figure Thirty. Measurement results of the two port filter 24 hours later, but with re-calibration applied to the channel. The memory trace shows the initial measurement result.

3.6.2 Residual Error after Re-Calibration

Notice in the plot that the results after re-calibration are different from the original data by ~ 0.03 dB. This is a small error, but it is a residual error caused by the transmission tracking term and load match terms not being updated during the re-calibration. These error terms are initially measured when the through calibration standard is connected between the ports during the base calibration.

The re-calibration intentionally does not measure the through standard since that step requires the user to disconnect the DUT and instead connect the through between the calibration planes.

So it is a deliberate trade off in order to enable the in-situ re-calibration. If this residual error is too large, the user has the option to connect a through and repeat the baseline calibration at any time.

In special cases the DUT itself can be used as the through, which also allows the baseline calibration to be repeated at any time.

4 Summary

The Inline Calibration Units offer a new convenience to VNA based measurement systems.

Even more important is that they offer a way to improve measurement accuracy by allowing re-calibration prior to any critical measurement. As demonstrated in the example in the previous section, there is no need to disconnect and reconnect cables or even move cables during the re-calibration step. This eliminates two very large sources of measurement error in any VNA based measurement system.

In conclusion: The new R&S Inline Calibration Units offer both convenience to the user and improved measurement accuracy.

5 References

[1] *Fundamentals of Vector Network Analysis*, by Michael Hiebel, 2007. Available for purchase from Rohde&Schwarz, order number 0002.6729.00.

[2] *1MA99: Guidance on Selecting and Handling Coaxial RF Connectors used with Rohde & Schwarz Test Equipment* Application Note which can be downloaded from www.rohde-schwarz.com

[3] Inline Calibration Unit Operating Manual, order number 1177.6381.02

[4] Inline Calibration Unit Data Sheet

[5] DHCP Server Software for Windows can be found at: http://www.dhcpserver.de/cms/

6 Ordering Information

Designation	Type	Order no.
Inline Calibration Unit Controller for R&S®ZN-Z32, R&S®ZN-Z33. Support of two CAN bus lines with up to 24 units each. incl. 2xR&S®ZN-CAN2	R&S®ZN-Z30	1328.7609.02
Inline Calibration Unit: Basic calibration and calibration refresh including temperature characterization 10 MHz to 8.5 GHz incl. 1xR&S®ZN-CAN025	R&S®ZN-Z32	1328.7638.02
Inline Calibration Unit: Basic calibration and calibration refresh Incl. temperature characterization 10 MHz to 40 GHz incl. 1xR&S®ZN-CAN025	R&S®ZN-Z33	1328.7644.02
Inline Calibration Unit: Basic calibration and calibration refresh Incl. temperature characterization 10 MHz to 40 GHz incl. 1xR&S®ZN-CAN025 TVAC version.	R&S®ZN-Z33	1328.7644.03
CAN-bus cable for Inline cal. modules (250 mm)	R&S®ZN-CAN025	1339.3622.02
CAN-bus cable for Inline cal. modules (2 m)	R&S®ZN-CAN2	1339.3639.02
CAN-bus cable for Inline cal. modules (10 m)	R&S®ZN-CAN10	1339.3645.02
CAN-bus adapter cable for to extend CAN-bus cable length by connecting R&S®ZN-CANx cables (250mm)	R&S®ZN-CANA	1339.3651.02
Application SW for Control of ZN-Z3x Inline Calibration Units (download R&S website)	R&S®ZN-Z3ASW	xxx

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