

Using S-Parameters with R&S® NRP-Z Power Sensors Application Note

Products:

| R&S® NRP-Z Sensors



S-parameter correction compensates for the losses and reflections introduced by a component – such as an attenuator, directional coupler, or matching pad – that is attached to a power sensor. Using S-parameters instead of a fixed offset makes measurements more accurate by accounting for the interaction between the sensor and a component. This shifts the sensor's reference plane from the sensor's RF connector to the input of the device that is being applied externally.

This application note explains the fundamentals of using S-parameters and discusses some common applications in which S-parameter correction is useful. It also introduces a command line tool for updating S-parameter data in custom applications or in automated test setups.

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1 Notices

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2 Overview

S-parameter correction compensates for the losses and reflections introduced by a component – such as an attenuator, directional coupler, or matching pad – that is attached to a power sensor. Using S-parameters instead of a fixed offset increases measurement accuracy by accounting for the interaction between the sensor and the component. As a result, the sensor's reference plane shifts from the sensor's RF connector to the input of the device being applied externally. This procedure is also referred to as *embedding* a device.

This application note briefly explains the fundamentals of S-parameter compensation and discusses some common applications for which embedding an external device is useful.

S-parameter data is stored as part of the sensor's internal calibration table. Therefore, it needs to be flashed into the sensor's non-volatile memory. To enable users to do this, the R&S®NRP toolkit includes a tool that is operated via a graphical user interface.

For applications in which S-parameters will be written to the sensor from custom applications, such as automated test setups, a command line tool is provided with this application note. To ensure compatibility with a large number of network analyzers, the tool can process measurement data files in the s2p format. It also supports all standard frequency units (Hz, kHz, MHz, GHz) and display formats (real and imaginary part, linear magnitude and phase, magnitude in dB, and phase). The only restriction is that a reference impedance of 50 ohms must be used for the S-parameters. The system ignores additional noise parameters in the s2p file.

3 Fundamentals

All R&S®NRP-Z power sensors make it possible to compensate for the influence of any two-port devices between the signal source and the sensor input. As a result, it is possible to calculate the power P that the signal source actually delivers. Examples of such two-port devices include attenuators, matching pads, minimum-loss pads and waveguide adapters. One precondition for such compensation is that a complete set of S-parameter data must be available for the two-port device in the frequency range required by the application.

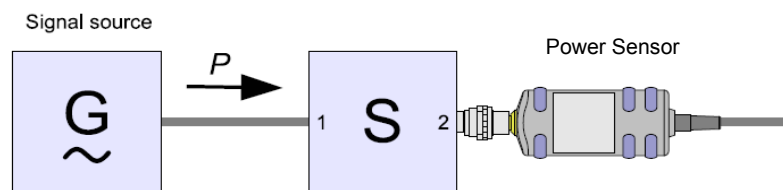


Fig. 1: Schematic view of embedding a device

The sensor's internal set of factory calibration data contains a table with frequency points that cover the entire operating frequency range of the sensor. Users can select the frequency points in the two-port S-parameter table independently of the sensor's factory calibration frequencies, which allows optimal coverage of the two-port frequency range of interest. The S-parameter's real parts and the imaginary parts are interpolated linearly between the frequency points. For the range below the first and above the last frequency, the values of the first and the last frequency are used, respectively.

S-parameter data sets are stored in the sensor's internal calibration data structure. As a result this data is not lost during a device reset or a power cycle. In addition, S-parameter data can be configured such that it becomes active automatically when the sensor is powered up. This feature is useful if a two-port device such as an attenuator pad is permanently attached to a sensor.

3.1 Scattering Parameters

RF circuits are often described using wave quantities. As a general rule, incident wave quantities are named a_x , while reflected wave quantities are named b_x . The unit for these values is \sqrt{W} .

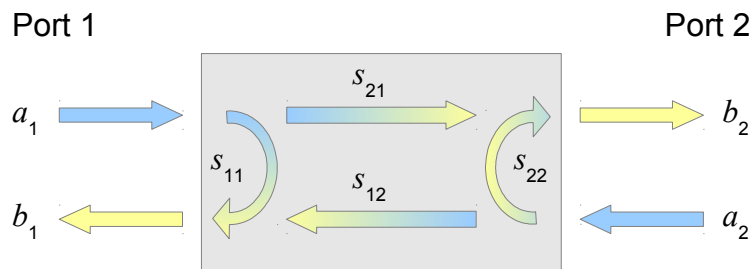
The complex reflection coefficient Γ denominates the relation between the reflected and the incident wave:

$$\Gamma = \frac{b}{a} \tag{3.1.1}$$

The reflection coefficient can also be calculated from the complex input impedance Z . The equation below uses the normalized impedance z :

$$\Gamma = \frac{z-1}{z+1} \quad \text{with} \quad z = \frac{Z}{Z_0} \quad Z_0 = \text{Ref. Impedance} \tag{3.1.2}$$

A two-port device is probably the most commonly used part in RF circuits. It is described by the four scattering parameters S_{11} , S_{21} , S_{22} , and S_{12} .



The variables a and b are used for the incident and the reflected wave.

$$b_1 = s_{11} a_1 + s_{12} a_2 \tag{3.1.3}$$

$$b_2 = s_{21} a_1 + s_{22} a_2 \tag{3.1.4}$$

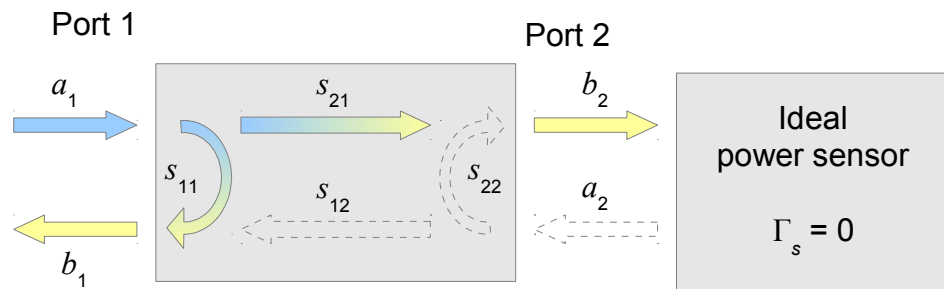
The relationships between all the parameters are often described by the matrix equation below. The matrix contains the scattering parameters for the two-port device.

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \tag{3.1.5}$$

3.2 Two-Port Devices

This section provides a step-by-step introduction to the fundamentals of working with the two-port devices that are connected to a power sensor.

The first example discusses the equations for situations in which an ideal power sensor is connected to a two-port device. Ideal sensors have the special characteristic that they are perfectly matched with the line impedance Z_0 . Therefore, they do not reflect any power back into the two-port device. Such sensors have a complex reflection coefficient Γ of zero.



The equations that describe this scenario are relatively simple, because the reflected wave a_2 is zero. As a result, the scattering parameters s_{22} and s_{12} have no effect.

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \begin{bmatrix} a_1 \\ a_2 \end{bmatrix} \quad \text{with} \quad a_2 = 0 \quad (3.2.1)$$

$$\begin{aligned} b_1 &= s_{11} a_1 \\ b_2 &= s_{21} a_1 \end{aligned}$$

Power sensors are always calibrated to measure the incident wave b_2 . This value is only affected by scattering parameter s_{21} , which is referred to as the insertion loss when it is expressed in dB.

$$s_{21} = 10^{-Loss_{dB}/20} \quad (3.2.2)$$

Real power sensors reflect a small portion of their incident wave back into the two-port device (a_2). The two-port device reflects a fraction of this wave back into the power sensor, where it adds to the power sensor's incident wave.

The power that the power sensor reflects can be described by the power sensor's incident wave and its reflection coefficient:

$$a_2 = \Gamma_s b_2 \quad (3.2.3)$$

The matrix equation for the entire system is:

$$\begin{bmatrix} b_1 \\ b_2 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} \\ s_{21} & s_{22} \end{bmatrix} \cdot \begin{bmatrix} a_1 \\ \Gamma_S b_2 \end{bmatrix} \quad (3.2.4)$$

As mentioned above, all power sensors are calibrated to measure the incident wave b_2 . The incident wave of the power sensor including the two-port device can be calculated by rearranging the above equations as follows:

$$a_1 = b_2 \frac{1 - s_{22} \Gamma_S}{s_{21}} \quad (3.2.5)$$

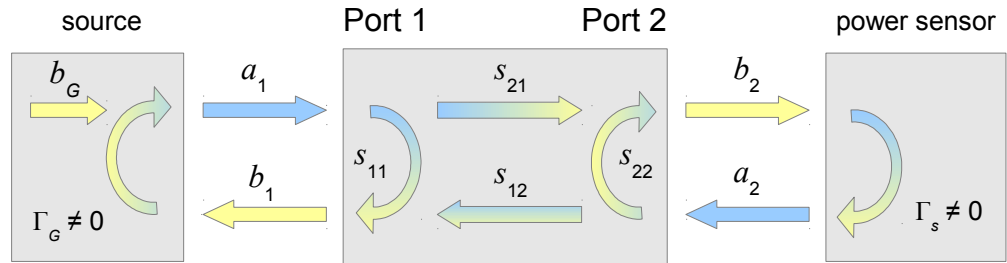
The power sensor uses this equation in combination with its internally stored gamma values Γ_S when S-parameter device data is loaded and activated in the sensor and the source gamma is not specified.

The difference between using a simple offset table (only s_{21} values) and using the S-parameter correction can be significant.

$$Error_{\%} \approx \pm 100 \% \left[(1 + s_{22} \Gamma_S)^2 - 1 \right] \quad (3.2.6)$$

As an example we examine a well-matched power sensor that is connected to a two-port device, such as a filter or an attenuator. The power sensor is assumed to provide a VSWR of 1.15. This sensor is connected to a two-port device with a VSWR of 1.35. The measurement error that results from using the simple offset table is $\pm 2.1\%$.

Realistic setups rarely use ideal sources. In such cases, the additional source reflection coefficient Γ_G needs to be included in the equations. We introduce the variable b_G as the source's output.



The forward wave a_1 that enters into the two-port device is calculated from the sum of the source power and from the amount of power that the source reflects:

$$a_1 = b_G + \Gamma_G b_1 \quad (3.2.7)$$

From the matrix equation (3.2.4) and the relationship between a_1 and b_1 , we can calculate the ratio of b_2 and b_G :

$$b_G = b_2 \left[\frac{(1 - s_{22} \Gamma_S)(1 - s_{11} \Gamma_G)}{s_{21}} - \Gamma_G \Gamma_S s_{12} \right] \quad (3.2.8)$$

This equation includes the S-parameter device, the power sensor's reflection coefficient, and the source reflection coefficient. The sensor firmware uses this

equation when the source reflection coefficient is also specified (when gamma correction is enabled).

The measurement error caused by using the simple offset table can be calculated from the following equation:

$$Error_{\%} \approx \pm 100 \% \left[\left(2 - (1 - s_{22} \Gamma_S)(1 - s_{11} \Gamma_G) \right)^2 - 1 \right] \quad (3.2.9)$$

4 Application Examples

4.1 High-Power Attenuators

Many applications require precise measurement of RF powers of up to several watts or even kilowatts. To achieve this, a high-power attenuator pad can be attached to the R&S NRP-Z power sensor.



The S-parameter correction capabilities compensate for frequency-dependent losses and reflections that the attenuator pad causes. This creates a precise USB power sensor that can be used to measure high-power signals.

The power sensor uses equation (3.2.8) when the S-parameter correction is enabled and the complex source reflection coefficient is provided (gamma correction enabled). The source's complex reflection coefficient Γ_G is not part of the S-parameter set. Instead, it must be provided for the operating frequency of interest in I/Q format or as phase and amplitude. When source gamma correction is not used, this value is assumed to be zero. In this case the simpler equation (3.2.5) is used by the sensor firmware.

The attenuator's S-parameter set does not necessarily need to cover the power sensor's entire frequency range. The number of frequency points in the S-parameter set should be selected to cover the frequency range needed for the application. The sensor uses linear interpolation between adjacent S-parameter frequency points. For frequencies below the ones defined in the S-parameter set, the sensor uses the S-parameter data for the lowest available frequency in the S-parameter data set. The same mechanism is used for frequencies higher than the maximum frequency that has been defined in the set.

The maximum permissible number of frequency points depends on the sensor model. It can be found in the data sheet in the "Embedding" section. Most sensors permit up to 1000 points.

The attenuator introduces a significant amount of level attenuation into the signal path. As a result, this attenuation affects the sensor's over-range indication as well as

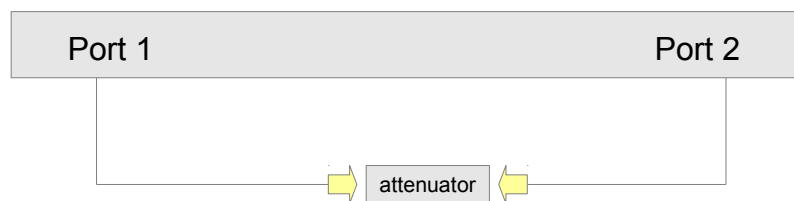
parameters that are related to a certain RF power level, e.g. the trigger threshold. Besides the data stored in the S-parameter data set, the sensor needs an estimated operating-power range when used with the attenuator. This updated power range can be set when the S-parameter data is written into the sensor.

The following steps outline the procedure for characterizing an attenuator pad using N-connectors on both ends:

1. Setup your network analyzer with all cabling to provide a 50 ohm reference plane (N-male) on port 2. Setup port 1 to provide a 50 ohm reference plane (N-female). Port 2 of the two-port device is later connected to the power sensor.



2. Configure the connectors and impedances used with the ports, as well as the desired frequency range, in the network analyzer user interface. The number of points depends on the sensor model and can be found in the sensor's data sheet in the section entitled "Embedding". Most sensors support at least 1000 points.
3. Calibrate both ports using either the R&S®ZCAN 50 calibration kit. The calibration type should be set to OSM.
4. Now connect the attenuator and measure the S-parameters. Then export the S-parameter set as a s2p file containing real and imaginary numbers.



5. Use the graphical tool provided with the R&S®NRP-Toolkit or the command line tool bundled with this application note to flash the S-parameter file into the power sensor. The sensor's power range increases by the attenuation of the attenuator pad. This updated power range must be specified in both tools.

4.2 75 Ohm Matching Pads

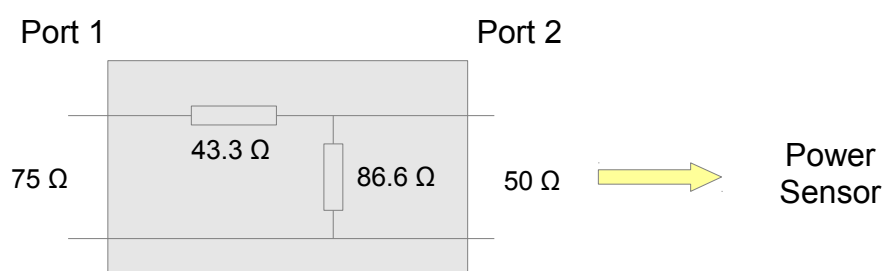
Consumer products in the cable and satellite TV markets typically use a reference impedance of 75 ohms. There is only a small number of power sensors available that are specifically designed for this impedance, and their frequency range is limited. One easy solution to this problem is to combine a regular R&S®NRP-Z universal power sensor with a 75 ohm matching pad (minimum loss pad).



Fig. 2: R&S®NRP-Z Power Sensor with Rosenberger minimum-loss pad

In this application, the matching pad's S-parameter set, including any required connectors, is measured with a network analyzer, and the results are stored inside the sensor. As a result, the matching pad's characteristics are embedded into the sensor, and the sensor's reference plane shifts to the matching pad's 75 ohm port.

The drawing below shows the internal construction of a standard 50 ohm/75 ohm minimum-loss pad. The insertion loss for this network is 5.72 dB.

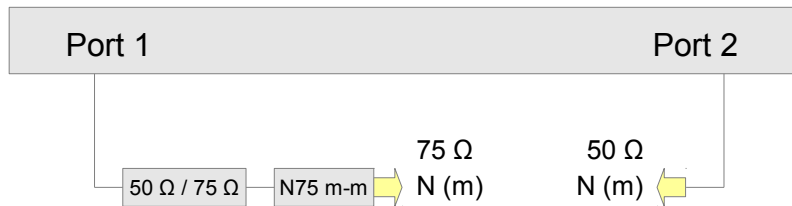


Minimum-loss pads for test and measurement applications are available from various vendors. The following table lists products with N-type connectors on both sides.

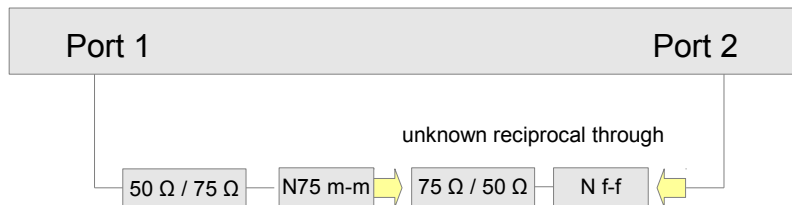
	50 Ohm	75 Ohm	Frequency
R&S®RAM	N (m)	N (f)	DC to 2.7 GHz
Rosenberger 53S173-K00	N (m)	N (f)	DC to 2 GHz
Mini Circuits UNMP-5075-33+	N (f)	N (m)	DC to 3 GHz
HP 11852B	N (f)	N (m)	DC to 3 GHz
HP 11852B Opt 004	N (m)	N (f)	DC to 3 GHz

In principle, all of the statements that have been made regarding high-power attenuators also apply to matching pads. Compared to an attenuator with both ports using the reference impedance of 50 ohms, characterizing a matching pad is slightly more complex. This is because one port uses a reference impedance of 75 ohms. As a result, a second matching pad and a 75 ohm calibration kit is required to characterize the device. The following steps outline the procedure for characterizing the Rosenberger minimum-loss pad or the R&S®RAM:

1. Setup your network analyzer with all cabling to provide a 50 ohm reference plane (N-male) on port 2. Setup port 1 with the minimum-loss pad to provide a 75 ohm reference plane (N-male).



2. Configure the connectors and impedances used with the ports, as well as the desired frequency range, in the network analyzer user interface. The number of points depends on the sensor model and can be found in the sensor's data sheet in the section entitled "Embedding". Most sensors support at least 1000 points.
3. Calibrate both ports using either the R&S®ZCAN 50 or R&S®ZCAN 75 calibration kit. The calibration type must be set to UOSM. Use a second minimum-loss pad in combination with a N-type F-F-adaptor (on the 50 ohm side) for the through-calibration.



4. Leave this combination and measure the S-parameters. Then export the S-parameter set as a s2p file containing real and imaginary numbers.
5. Use the graphical tool provided with the R&S®NRP-Toolkit or the command line tool bundled with this application note to flash the S-parameter file into the power sensor. The matching pad's insertion loss is 5.72 dB. The sensor's power range therefore increases by about 6 dB. This updated power range must be specified in both tools.

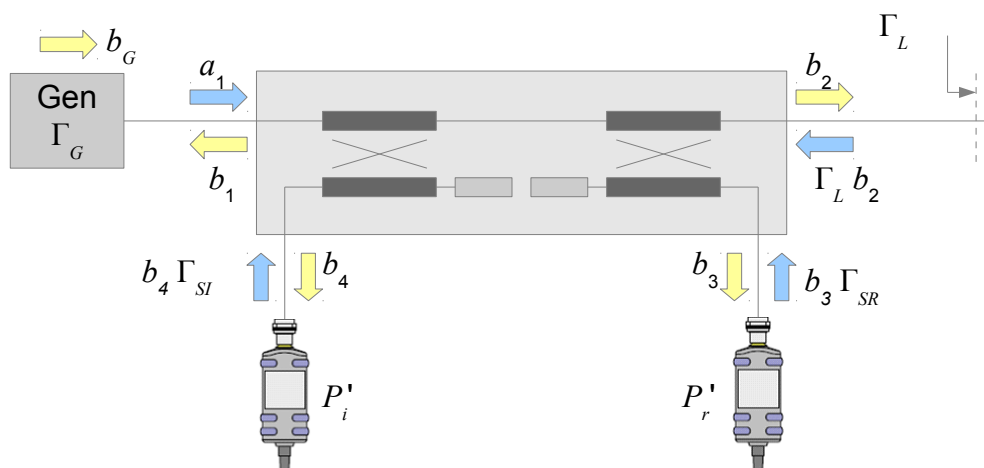
4.3 Directional Couplers

In applications in which forward and reverse power need to be measured precisely, a directional power meter is often the instrument of choice. These power meters combine two RF detectors and a high-directivity directional coupler in a single instrument. One drawback here is that the choice of directional power meters is limited with respect to their measurement capabilities and frequency ranges. Therefore, an alternative solution is to combine two R&S® NRP-Z power sensors with a high-directivity directional coupler. This solution also provides the advantage that the coupler can be selected to match the application's requirements.

Typical task that can be performed with such setups are:

- Monitoring the generator power
- Monitoring the forward power into the DUT
- Monitoring the load gamma, e.g. for antennas

The diagram below shows the setup and indicates all parameters of interest. The directional coupler is connected between a power source and a load. Both the generator and the load have a reflection coefficient greater than zero. The coupled ports are connected to power sensors which also reflect a small portion of their incident power back into the coupler.



The following matrix equation fully describes this system. The vector with the input signals on the right side already uses the combination of the output power and the reflection coefficient.

$$\begin{bmatrix} b_1 \\ b_2 \\ b_3 \\ b_4 \end{bmatrix} = \begin{bmatrix} s_{11} & s_{12} & s_{13} & s_{14} \\ s_{21} & s_{22} & s_{23} & s_{24} \\ s_{31} & s_{32} & s_{33} & s_{34} \\ s_{41} & s_{42} & s_{43} & s_{44} \end{bmatrix} \cdot \begin{bmatrix} \Gamma_G b_1 + b_G \\ \Gamma_L b_2 \\ \Gamma_{SR} b_3 \\ \Gamma_{SI} b_4 \end{bmatrix} \quad (4.3.1)$$

Before discussing the relationship between different values, it is useful to introduce a few commonly used parameters. These parameters are important for selecting a directional coupler that best fits an application.

The **coupling coefficient** describes the ratio of the incident power that is fed into the main port to the coupled port power. This figure is specified when all ports are terminated so that no power is reflected back into the directional coupler. The value is typically expressed in dB (related to power).

$$\begin{aligned}C_{forward} &= -20 \log |s_{41}| \text{ dB} \\C_{reverse} &= -20 \log |s_{32}| \text{ dB}\end{aligned}\tag{4.3.2}$$

Another very important figure is the coupler's **directivity**. It describes the power ratio measured at the coupled port when the same amount of power is transmitted in the desired direction or in the opposite direction. This value is expressed in dB. It is also assumed that none of the ports reflect power back into the coupler. This application requires directivity values of at least 20 dB. Reflectometer couplers often provide a directivity of up to 45 dB.

$$\begin{aligned}d_{fwd} &= -20 \log \left| \frac{s_{42}}{s_{41}} \right| \text{ dB} \\d_{rev} &= -20 \log \left| \frac{s_{31}}{s_{32}} \right| \text{ dB}\end{aligned}\tag{4.3.3}$$

The **main-line loss** describes the change in load power that is caused by inserting the coupler into the system.

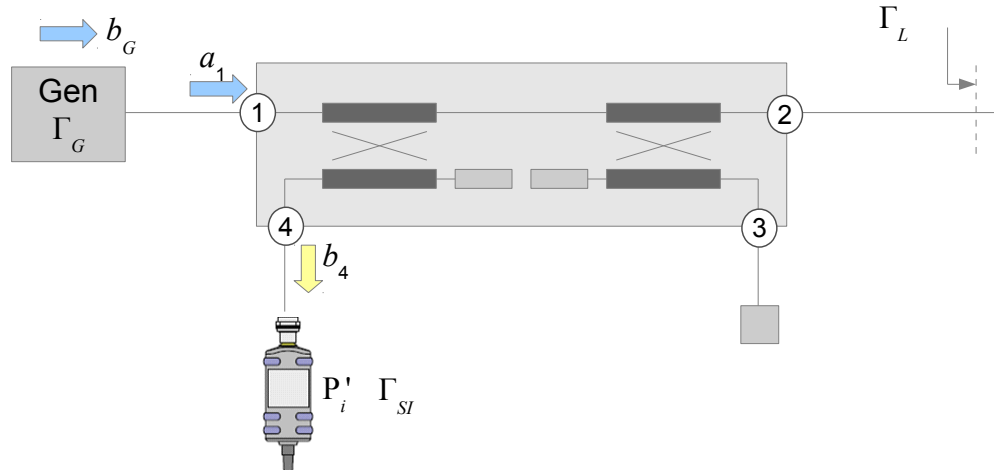
$$\frac{b_2}{a_1} = \frac{s_{21}}{1 - \Gamma_L s_{22}}\tag{4.3.4}$$

The main-line loss is specified when the coupler's output is perfectly terminated. In this case the denominator in the above equation is one.

$$ML_{dB} = -20 \log |s_{21}|\tag{4.3.5}$$

4.3.1 Measuring the Generator Power

In setups intended for monitoring the generator power, it is common practice to calculate this value from the power measured at port 4. The diagram below shows this setup and denominates all parameters of interest.



The relationship a_1/b_4 is mainly determined by the coupler's coupling ratio, S_{41} . This, however, is a greatly simplified assumption, because it ignores all reflections caused by the devices connected to the coupler ports. In order to take more precise measurements, it is necessary to evaluate the complete matrix equation (4.3.1). Eliminating all unnecessary parameters leads to a relatively large expression for the relationship a_1/b_4 . Therefore, a few assumptions can be made upfront to reduce the complexity. The first simplification is that coefficients s_{43} and s_{34} can be set to zero. This assumption is valid in most cases, because typical coupling ratios are in the order of 10 dB to 20 dB, and these two S-parameters are in the order of twice the sum of the forward and the reverse coupling ratio. The second assumption is that the reflection back into port 3 is ignored for the measurement at port 4. This is also a valid assumption, because power sensors typically use good matching. The remaining portion of the equation is as follows:

$$\frac{b_4}{a_1} \approx \frac{s_{41}}{1 - \Gamma_{SI} s_{44}} \left[\frac{1 + d_{fwd} \Gamma_L s_{21} - \Gamma_L s_{22}}{1 - \Gamma_L s_{22} - d_{fwd} \Gamma_L \Gamma_{SI} \frac{s_{24} \cdot s_{41}}{1 - \Gamma_{SI} s_{44}}} \right] \quad (4.3.6)$$

It is possible to further simplify this equation by removing the term $d_{fwd} \Gamma_L \Gamma_{SI}$ in the denominator. That assumption is valid, because the product of the directivity and the two reflection coefficients is minor compared to the other terms. The remaining part of the equation can then be rearranged into the following form:

$$\frac{b_4}{a_1} \approx \frac{s_{41}}{1 - \Gamma_{SI} s_{44}} \left[1 + d_{fwd} \Gamma_L \frac{s_{21}}{1 - \Gamma_L s_{22}} \right] \quad (4.3.7)$$

In the next step, we compare this equation with the two-port equation used inside the sensor (3.2.5). From this comparison, we can derive assignment rules that show how the two-port S-parameters used by the sensor's firmware need to be determined from the measured S-parameters. In the equations below the two-port S-parameters are named S'_{xy} .

$$s'_{11} = 0 \quad (4.3.8)$$

$$s'_{21} = s_{41} \left[1 + d_{fvd} \Gamma_L \frac{s_{21}}{1 - \Gamma_L s_{22}} \right] \approx s_{41} \left[1 + d_{fvd} \Gamma_L s_{21} \right] \quad (4.3.9)$$

$$s'_{22} = s_{44} \quad (4.3.10)$$

$$s'_{12} = 0 \quad (4.3.11)$$

Equation (4.3.9) shows the main impact of the load matching and coupler directivity on our measurement result. It is useful for estimating the measurement error caused by poor coupler directivity. The following example shows a typical configuration:

Directivity	15 dB	$d_{fvd} = 0.178$
VSWR Load	1.8	$\Gamma_L = 0.286$
VSWR Port 2	1.25	$s_{22} = 0.111$
Insertion Loss	1 dB	$s_{21} = 0.891$

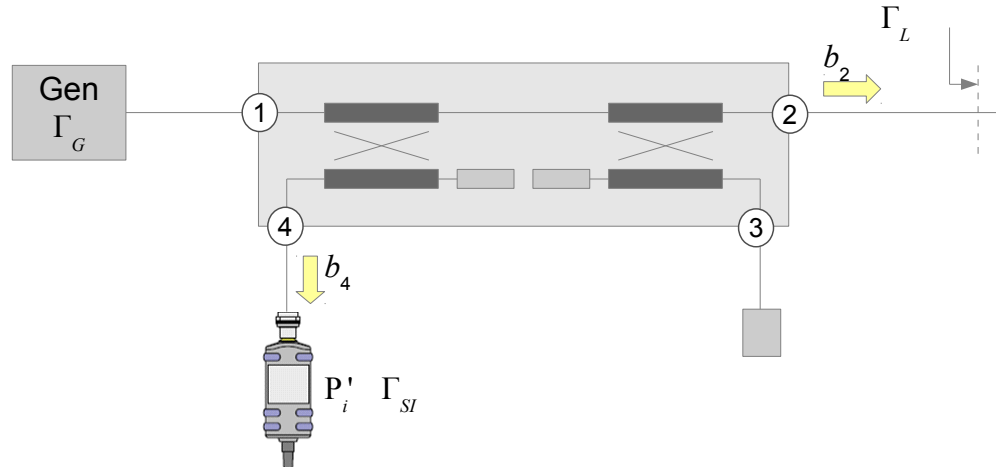
$$|s'_{21}| = |s_{41}| \left[1 \pm 0.178 \cdot 0.286 \frac{0.891}{1 \mp 0.286 \cdot 0.111} \right] = s_{41} (1 + 0.047) \quad (4.3.12)$$

$$Error_{\%} \approx 100\% [1.047^2 - 1] = 9.6\% \quad (4.3.13)$$

The power measurement error introduced by the low directivity and the load reflection coefficient is 9.6 %.

4.3.2 Measuring the Forward Power

In applications that require monitoring of the forward power into the DUT, it is common practice to calculate this value from the measured value at the coupled port, port 4. The drawing below shows the setup and all parameters of interest:



The equation below shows the relationship between measured value b_4 and the power being fed into the DUT (b_2). As in the previous chapter, S-parameters S_{43} and S_{34} are ignored. In addition, we assume that the power sensor connected to port 3 does not reflect power back into the directional coupler. These two assumptions simplify the equation dramatically.

$$\frac{b_4}{b_2} \approx \frac{s_{41}}{1 - \Gamma_{SI} s_{44}} \cdot \frac{1 + d_{fwd} \Gamma_L s_{21} - \Gamma_L s_{22}}{s_{21} + \Gamma_{SI} s_{24} \frac{s_{41}}{1 - \Gamma_{SI} s_{44}}} \quad (4.3.14)$$

That equation can be slightly rearranged, and the reverse directivity can be used for the ratio of s_{42}/s_{41} (assuming that $s_{42} = s_{24}$).

$$\frac{b_4}{b_2} \approx \frac{s_{41}}{1 - \Gamma_{SI} s_{44}} \cdot \frac{1 + \Gamma_L (d_{fwd} s_{21} - s_{22})}{s_{21} + d_{rev} \frac{s_{41}^2}{1 - \Gamma_{SI} s_{44}}} \quad (4.3.15)$$

The impact of the second term in the denominator of the ratio on the right is typically well below 0.1 %, and it can often be ignored in the equation. This leads to a greatly simplified equation that provides a good approximation of the ratio b_4/b_2 .

$$\frac{b_4}{b_2} \approx \frac{s_{41}}{1 - \Gamma_{SI} s_{44}} \cdot \frac{1 + \Gamma_L (d_{fwd} s_{21} - s_{22})}{s_{21}} \quad (4.3.16)$$

Comparing this with the two-port equation leads to the relationship between the two-port S-parameters S'_{xy} required by the sensor's firmware and the parameters measured in this setup.

$$s'_{11} = 0 \quad (4.3.17)$$

$$s'_{21} = s_{41} \frac{1 - \Gamma_L s_{22}}{s_{21}} + d_{fwd} \Gamma_L \quad (4.3.18)$$

$$s'_{22} = s_{44} \quad (4.3.19)$$

$$s'_{12} = 0 \quad (4.3.20)$$

In all cases with significant load reflection, the S-parameters measured for the directional coupler must be transformed using the above equations. The resulting two-port S-parameters can then be loaded into the sensor.

If the load reflection can be ignored, the equation (4.3.18) can be reduced to this very simple form:

$$s'_{21} = \frac{s_{41}}{s_{21}} \quad (4.3.21)$$

5 Updating S-Parameters

The S-parameter device data is part of the sensor's calibration data. This data contains important data that was written to the sensor during production. Therefore, it is very important that the entire calibration data be backed up to a file before alterations are made. Updating S-parameter data is, therefore, only possible using the graphical tools provided with the R&S®NRP Toolkit or using the command line application provided with this application note. Both of these tools ensure that the sensor calibration data is securely saved to the local hard drive before attempting to flash the sensor's calibration tables. If the update procedure fails, the backup calibration data can be restored from this file.

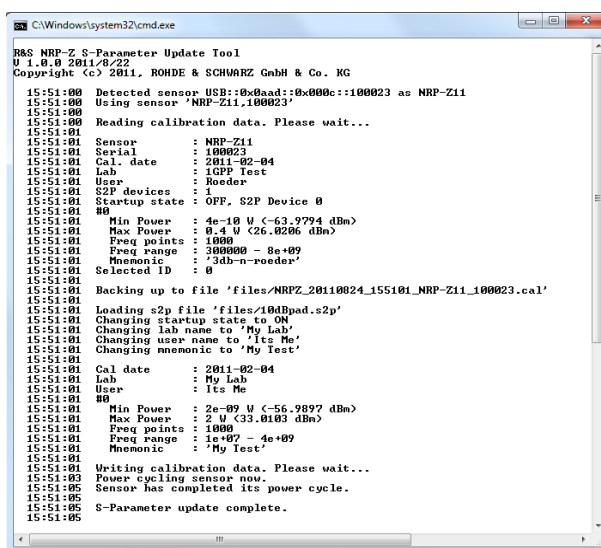
The graphical tool is provided with the R&S®NRP Toolkit and described in the sensor's user manual. Please refer to that manual for further information about this tool.

The command line application is mainly intended for applications for which S-parameters need to be flashed unattended, e.g. for custom software or automated test systems. The tool is available for Microsoft Windows-based operating systems. The following configuration was tested by Rohde & Schwarz at the time of writing:

- Windows XP; or Windows 7, 32-bit and 64-bit
- R&S®NRP Toolkit 2.1.18

The software first connects to the selected sensor. Then it reads out the entire calibration data block and writes it to a backup file. If it is not possible to write to that file, the software does not continue sending any data back to the sensor. In the next step, all alterations are made in the S-parameter correction tables, and a summary of the changes is printed to the console. In the last step, the sensor's calibration data is updated and subsequently power cycled.

Various return codes allow the calling application to determine if the update completed successfully or if an error occurred.



```
R&S NRP-Z S-Parameter Update Tool
U 1.0.0 2011/8/22
Copyright (c) 2011, ROHDE & SCHWARZ GmbH & Co. KG

15:51:00 Detected sensor USB:\Device\NPF{...} as NRP-Z11
15:51:00 Using sensor 'NRP-Z11_100023'
15:51:01 Reading calibration data. Please wait...
15:51:01 Sensor : NRP-Z11
15:51:01 Serial : 100023
15:51:01 Cal. date : 2011-02-04
15:51:01 Lab : IGP Test
15:51:01 User : Roeder
15:51:01 S2P devices : 1
15:51:01 Startup state : OFF, S2P Device 0
15:51:01 #0
15:51:01 Min Power : 4e-10 W (-63.9794 dBm)
15:51:01 Max Power : 0.4 W (26.0286 dBm)
15:51:01 Freq points : 1000
15:51:01 Freq range : 3000000 - 8e+09
15:51:01 Mnemonic : '3db-n-roeder'
15:51:01 Selected ID : 0
15:51:01
15:51:01 Backing up to file 'files\NRPZ_20110824_155101_NRP-Z11_100023.cal'
15:51:01
15:51:01 Loading s2p file 'files\10dBpad.s2p'
15:51:01 Changing startup state to ON
15:51:01 Changing lab name to 'My Lab'
15:51:01 Changing user name to 'Its Me'
15:51:01 Changing mnemonic to 'My Test'
15:51:01
15:51:01 Cal date : 2011-02-04
15:51:01 Lab : My Lab
15:51:01 User : Its Me
15:51:01 #0
15:51:01 Min Power : 2e-09 W (-56.9897 dBm)
15:51:01 Max Power : 2 W (33.0103 dBm)
15:51:01 Freq points : 1000
15:51:01 Freq range : 1e+07 - 4e+09
15:51:01 Mnemonic : 'My Test'
15:51:01
15:51:01 Writing calibration data. Please wait...
15:51:03 Power cycling sensor now.
15:51:05 Sensor has completed its power cycle.
15:51:05
15:51:05 S-Parameter update complete.
15:51:05
```

5.1 S-Parameter Files

S2P files are human readable text files that contain header information as well as the complex S-parameters of the device under test in columns. This chapter briefly describes the format of the s2p file.

Any line starting with an exclamation mark (!) is interpreted as a comment line.

An s2p file always starts with the *option line*. This line has the following format:

[<frequency unit>] [<parameter>] [<format>] [<R n>]

The <frequency unit> may be Hz, kHz, MHz or GHz. When no frequency unit is specified, GHz is implicitly assumed.

The <parameter> is optional and must be 'S' if it is provided. When no parameter is specified, S is implicitly assumed.

The <format> may be MA (linear magnitude and phase in degrees), DB (magnitude in dB, phase in degrees) or RI (real and imaginary part). When no format is specified, MA is implicitly assumed.

R is optional and is followed by the reference impedance in ohms. If an entry is made for R, R50 must be specified. If no entry is made, R50 is implicitly assumed.

The measurement frequencies (in ascending order) are specified as follows:

f_i $S_{11}(f_i)$ $S_{21}(f_i)$ $S_{12}(f_i)$ $S_{22}(f_i)$,

where $S_{jk}(f_i)$ is the format as specified in the *option line*:

$|S_{jk}(f_i)|$ $\arg S_{jk}(f_i)$ Linear magnitude and phase in degrees

$20 \log_{10} |S_{jk}(f_i)|$ $\arg S_{jk}(f_i)$ Magnitude in dB and phase in degrees

Re $|S_{jk}(f_i)|$ Im $|S_{jk}(f_i)|$ Real and imaginary part

5.2 Multiple Sets of S-Parameters

Some R&S NRP-Z power sensor models support simultaneous loading of multiple S-parameter devices into the sensor. This feature is intended for automated test setups that switch the RF path to different configurations, which requires corresponding reconfiguration of the sensor.

The S-parameter set is addressed by an index number starting with zero. When the sensors only support a single S-parameter device, this index is always zero. In all other cases, the index can be selected between zero and the number of available S-parameters sets minus one.

5.3 Sensor Power Limits

The data sheet specifies an upper and lower power measurement limit for each power sensor. When the S-parameters are loaded and activated, the nominal lower and upper measurement limits typically change. This change results from the additional attenuation that is introduced by the two-port device connected to the power sensor. The set of limits applicable when an S-parameter device is enabled must be provided when the S-parameters are written into the sensor. This is because it is not always possible to derive these nominal limits from the combination of the sensor's limits and the two-port device's loss or gain. For example, the upper measurement limit for the sensor/two-port combination may be limited by the two-port's maximum power-handling capacity. Furthermore, the lower measurement limit may be raised. This can be caused by the two-port device's loss, but it can also be caused by its inherent noise. For this reason, the user can select these values.

6 Command Line Options

This chapter describes all command line options for the S-parameter update tool in great detail. Text in square brackets [] is optional. Text in angle brackets <> must be replaced with the correct text for the application.

General calling convention:

```
NrpSParaUpdate -sensor=<type>,<serial> [options]
```

Sensor selection:

```
-sensor=<type>,<serial>
```

This option is mandatory and selects the target sensor. The application requires exclusive access to this sensor. Use the full sensor name, e.g. NRP-Z11, as the type identifier. Blanks are not permissible anywhere in the option string.

Example: -sensor=NRP-Z11,100123

Backup directory:

```
-backupdir=<path>
```

This option sets the backup directory. Successfully backing up the sensor's calibration data is required before the software attempts to write S-parameter data back to the sensor. The file name is automatically generated and contains the date, time, and sensor serial number. If this option is not set, the software uses the user's home directory.

Example:	-backupdir=.	Local directory
	-backupdir=myData	Local sub-directory
	-backupdir=C:\Temp	Absolute directory
	-backupdir="C:\My Dir"	Absolute directory with

spaces

Only displaying S-parameter information:

```
-info
```

This options only displays the sensor information related to the S-parameters and then exits.

Restoring from a .cal file:

```
-restore=<filename>
```

This option is used to restore a previously saved backup file (.cal). The option may be combined with the other options related to S-parameters. In this case, the data saved in the .cal file is used as the baseline for all alterations.

Updating S-parameter data:

```
-s2p=<filename>
```

This option selects the S-parameter file that is to be processed and the data from it that is to be written into the sensor.

Setting the S-parameter device number:

```
-device=<device_id>
```

Some sensors support multiple S-parameter devices. If this option is omitted, the first S-parameter device is updated (device ID 0).

Defining the power limits:

```
-plim=<lower>,<higher>
```

The sensor's upper and lower power limits should be updated according to the embedded device's attenuation or gain. Both values are provided in watts. The sensor uses these two parameters to verify settings such as the trigger level. If this option is omitted, the program automatically tries to determine a reasonable range from the s_{21} parameter and the sensor's properties.

Setting the S-parameter device mnemonic:

```
-mnemonic=<name>
```

Each S-parameter device may have a name assigned to it. This name is referred to as the mnemonic, and it is particularly useful when multiple S-parameter devices are in use. This option should be used if the S-parameter data is updated using the -s2p option.

```
Example: -mnemonic="10dB Pad"
```

Setting the start-up mode:

```
-default=on|off
```

The start-up mode defines whether the S-parameter device is to be active when the sensor is powered on (or after a reset command). By default, the start-up state is set to "off," which means that the S-parameter device needs to be turned on explicitly. If this option is omitted, the current state is left unaltered.

Changing the lab or user name:

-labname=<lab>
-username=<user>

The sensor's calibration data contains optional fields that provide information on the lab and person responsible for the last calibration. If these options are omitted, the software leaves these entries untouched. The lab name cannot contain the string "R&S" or the words "Rohde" and "Schwarz" together.

Turing off the write functionality:

-nowrite

This option disables updating of the S-parameters and is mainly used for testing purposes.

7 Examples

Show help text:

```
NrpSParaUpdate
```

Read out sensor data:

```
NrpSParaUpdate -sensor=NRP-Z11,100123 -info
```

Only show and backup data to a specific directory:

```
NrpSParaUpdate -sensor=NRP-Z11,100123  
-backupdir=C:\Temp -nowrite
```

Only turn on default state:

```
NrpSParaUpdate -sensor=NRP-Z11,100123 -default=on
```

Update S-parameter data and power range:

```
NrpSParaUpdate -sensor=NRP-Z11,100123  
-s2p=10dBPad.s2p -plim=2e-9,2
```

Restore previously saved data:

```
NrpSParaUpdate -sensor=NRP-Z11,100123  
-restore=backupfile.cal
```

8 Ordering Information

Designation	Type	Order No.
Universal Power Sensors		
200 pW to 200 mW, 10 MHz to 8 GHz (cable length 1.6 m)	R&S®NRP-Z11	1138.3004.02
200 pW to 200 mW, 10 MHz to 8 GHz (cable length 0.4 m)	R&S®NRP-Z11	1138.3004.04
200 pW to 200 mW, 10 MHz to 18 GHz	R&S®NRP-Z21	1137.6000.02
2 nW to 2 W, 10 MHz to 18 GHz	R&S®NRP-Z22	1137.7506.02
20 nW to 15 W, 10 MHz to 18 GHz	R&S®NRP-Z23	1137.8002.02
60 nW to 30 W, 10 MHz to 18 GHz	R&S®NRP-Z24	1137.8502.02
200 pW to 200 mW, 10 MHz to 33 GHz	R&S®NRP-Z31	1169.2400.02
Two-Path Diode Sensors		
1 nW to 100 mW, 10 MHz to 8 GHz	R&S®NRP-Z211	1417.0409.02
1 nW to 100 mW, 10 MHz to 18 GHz	R&S®NRP-Z221	1417.0309.02
Wideband Power Sensors		
1 nW to 100 mW, 50 MHz to 18 GHz	R&S®NRP-Z81	1137.9009.02
1 nW to 100 mW, 50 MHz to 40 GHz	R&S®NRP-Z85	1411.7501.02
1 nW to 100 mW, 50 MHz to 40 GHz	R&S®NRP-Z86	1417.0109.40
Thermal Power Sensors		
1 µW to 100 mW, DC to 18 GHz	R&S®NRP-Z51	1138.0005.02
300 nW to 100 mW, DC to 33 GHz	R&S®NRP-Z52	1138.0005.02
300 nW to 100 mW, DC to 40 GHz	R&S®NRP-Z55	1138.2008.03
300 nW to 100 mW, DC to 44 GHz	R&S®NRP-Z55	1138.2008.04
300 nW to 100 mW, DC to 50 GHz	R&S®NRP-Z56	1171.8201.02
300 nW to 100 mW, DC to 67 GHz	R&S®NRP-Z57	1171.8401.02
300 nW to 100 mW, DC to 110 GHz	R&S®NRP-Z58	1173.7031.02
Average Power Sensors		
200 pW to 200 mW, 9 kHz to 6 GHz	R&S®NRP-Z91	1168.8004.02
2 nW to 2 W, 9 kHz to 6 GHz	R&S®NRP-Z92	1171.7005.02
2 nW to 2 W, 9 kHz to 6 GHz (incl. R&S®NRP-Z4 USB adapter cable var. 04 m, 0.5 m)	R&S®NRP-Z92	1171.7005.42
Level Control Sensors		
200 pW to 100 mW, 9 kHz to 6 GHz	R&S®NRP-Z98	1170.8508.02
200 pW to 100 mW, 10 MHz to 18 GHz	R&S®NRP-Z28	1170.8008.02
Power Sensor Modules		
4 µW to 400 mW, DC to 18 GHz	R&S®NRP-Z27	1169.4102.02
4 µW to 400 mW, DC to 26.5 GHz	R&S®NRP-Z37	1169.3206.02
Recommended Extras		
Sensor Extension Cable to 3 m	R&S®NRP-Z2	1146.6750.03

Sensor Extension Cable to 5 m	R&S®NRP-Z2	1146.6750.05
Sensor Extension Cable to 10 m	R&S®NRP-Z2	1146.6750.10
Panel-Mount Extension Cable to 5 m	R&S®NRP-Z2	1146.6750.15
USB Adapter (active), 2 m	R&S®NRP-Z3	1146.7005.02
USB Adapter (passive), 1.5 m	R&S®NRP-Z4	1146.8001.02
USB Adapter (passive), 0.5 m	R&S®NRP-Z4	1146.8001.02
USB Adapter (passive) for panel-mount, 1 m	R&S®NRP-Z4	1146.8001.11
USB Sensor Hub	R&S®NRP-Z5	1146.7740.02

About Rohde & Schwarz

Rohde & Schwarz is an independent group of companies specializing in electronics. It is a leading supplier of solutions in the fields of test and measurement, broadcasting, radiomonitoring and radiolocation, as well as secure communications. Established more than 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

Environmental commitment

- Energy-efficient products
- Continuous improvement in environmental sustainability
- ISO 14001-certified environmental management system

Certified Quality System
ISO 9001

Regional contact

Europe, Africa, Middle East
+49 89 4129 12345

customersupport@rohde-schwarz.com

North America

1-888-TEST-RSA (1-888-837-8772)

customer.support@rsa.rohde-schwarz.com

Latin America

+1-410-910-7988

customersupport.la@rohde-schwarz.com

Asia/Pacific

+65 65 13 04 88

customersupport.asia@rohde-schwarz.com

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Rohde & Schwarz GmbH & Co. KG

Mühlhofstraße 15 | D - 81671 Munich

Phone + 49 89 4129 - 0 | Fax + 49 89 4129 - 13777

www.rohde-schwarz.com