Coherence Measurement between two Signals regarding Timing, Phase and Gain
Application Note

Products:

- R&S®FS-Z10
- R&S®FSQ
- R&S®FSG
- R&S®SMU
- R&S®SMIQ
- R&S®SMBV

This application note describes how to measure the coherence (phase-, timing- and gain-differences) between two RF-Signals using Rohde&Schwarz spectrum analyzers, a Rohde&Schwarz signal generator and the R&S®FS-Z10 Coherence Unit.

Application Note

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ROHDE&SCHWARZ

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1 Overview

Numerous RF applications, such as multi-antenna communications, radar and beamforming systems, require the synchronous transmission of two or more signals. In practice, imperfections in the hardware can result in unwanted timing, gain and phase differences between the transmitted signals. Such differences must be accurately measured in order to calibrate the transmission system for correct operation. Therefore imperfections in the measurement system itself such as different cable properties, differences between the internal clocks of the signal analyzers, etc. must be taken into account.

The task of the Coherence Unit and the provided Remote Software is to enable accurate measurement of a two-antenna device under test by compensating for unwanted effects which arise in the measurement process. The provided software also allows the operator to compensate for differences in the transmitted signals originating from the DUT and save the results to file for later analysis. The measurement process requires an R&S Coherence Unit, two R&S spectrum analyzers (FSQ or FSG as master analyzer and FSQ, FSL or FSG as secondary analyzer), a R&S signal generator (e.g. SMU, SMIQ or SMBV) to generate a reference signal and a PC to run the software.

2 Coherence Measurement

2.1 The measurement task

The measurement task is to accurately measure the coherence between two RF-signals, i.e. to measure the timing, gain and phase differences between signals which originate from the two-antenna DUT. Disruptive factors caused by the test environment must be accounted for in the signal analysis. Such factors include:

- Thermal fluctuations that affect the channel characteristics and therefore interfere with the results.
- Inaccuracies caused by cables with different lengths, impedances, etc..
- Different trigger offsets between the connected analyzers.
- Local oscillator phase offsets between the connected analyzers.

The measurement problem description is depicted in Figure 1.

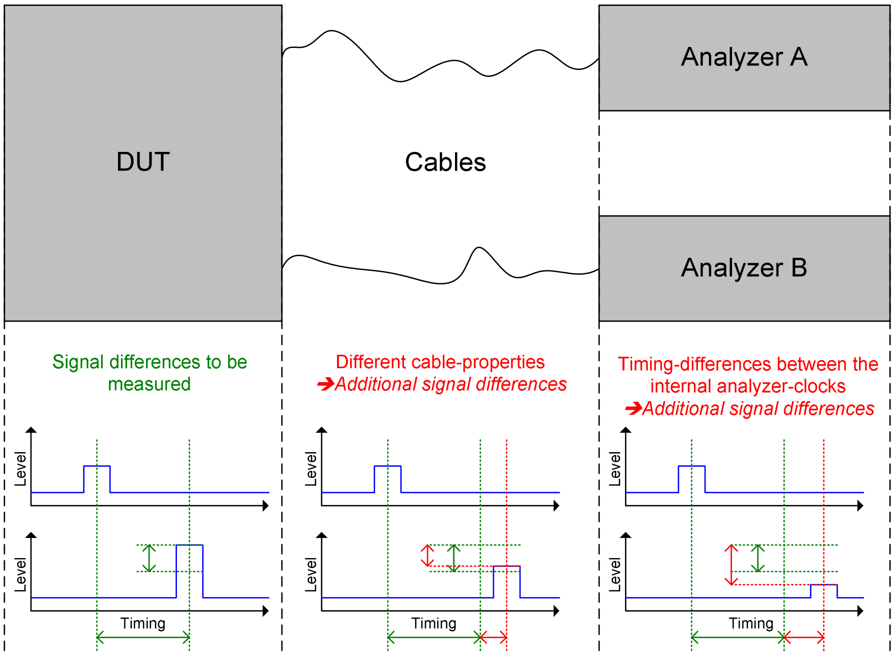


Figure 1: Measurement task

2.2 The Rohde & Schwarz Coherence Unit solution

The Rohde & Schwarz Coherence Unit, together with the accompanying Remote Control software, provides a comfortable solution to the measurement problem described in the previous section, which alleviates the need for:

- Calibrated measurement cables
- An isolated testing environment with constant temperature.
- Frequency or phase synchronization of signal analyzers

The Coherence Unit achieves this using:

- Periodic measurement of inaccuracies arising within the test environment (due to the factors described in Section 2.1) using a reference signal.
- Automatic compensation for measurement inaccuracies in the calculation of the DUT parameters.

2.2.1 Principles of operation

The measurement process involves three main steps which are repeated periodically:

1. Capture of the reference signal.
2. Capture of the DUT signals.
3. Analysis of the capture signals to determine the DUT parameters.

The reference signal used in the measurement process is supplied using a signal generator and is automatically split and directed to both signal analyzers at the beginning of each measurement. This approach ensures that two identical signals are available at the RF outputs of the FS-Z10 for estimation of inaccuracies caused by the cables and the spectrum analyzers. The reference signal path is indicated in yellow on the Coherence Unit's casing ("CAL IN → RF OUT 1|2", shown here in Figure 2).

Following the transmission of the reference signal, the signals from the DUT are switched through to the Coherence Unit's output terminals. The orange signal paths shown in Figure 2 ("RF IN 1|2 → RF OUT 1|2") are used during this step.

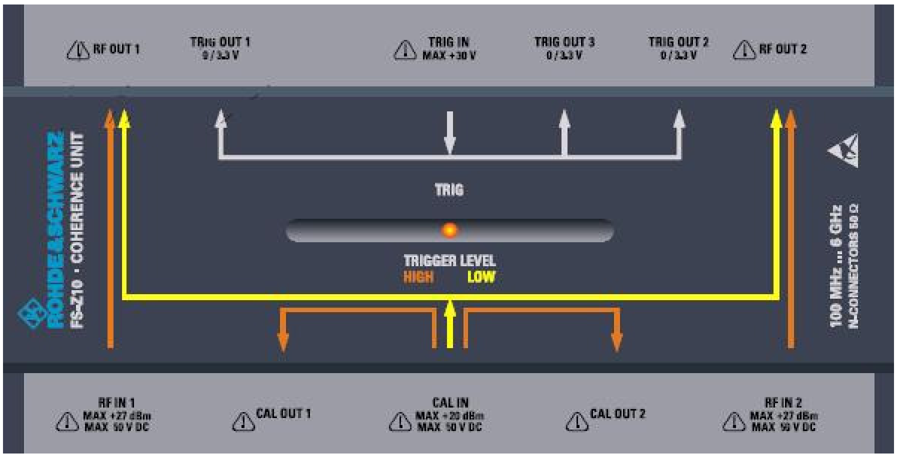


Figure 2: Coherence Unit Signalpaths

The structure of the captured signals, consisting of reference and measurement parts, is illustrated in Figure 3. The signal differences determined using the reference signals are automatically compensated by the analysis to ensure that the final measurement results will contain only the signal differences originating from the DUT.

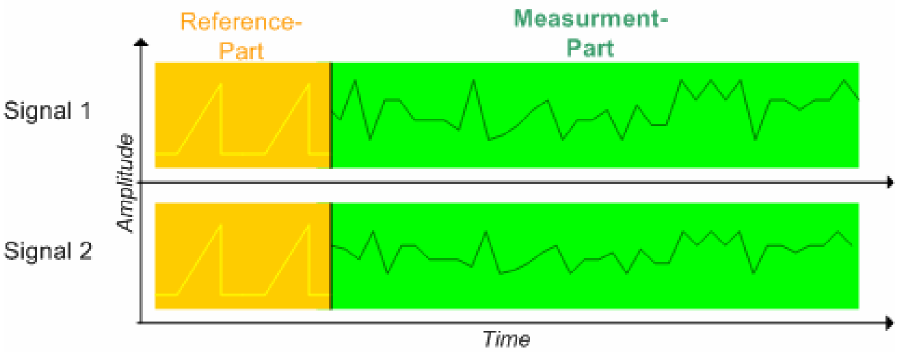


Figure 3: Data captured during a measurement

It is important to note that during the measurement process, the Coherence Unit Remote Software cannot determine the characteristics of the cables used to connect the DUT to the FS-Z10. The aforementioned switching of the signal paths can only be used to detect the differences that occur between the FS-Z10 and the signal analyzers. For this reason a calibration mode is provided, which can be used to estimate the cable parameters. For a detailed description of the calibration mode, see chapter 3.1.

3 How to perform the Coherence Measurement

3.1 Calibration of the Test Equipment

Before coherence measurements are conducted, it is recommended to calibrate the cables used to connect the DUT to the Coherence Unit. The aim of the calibration is to measure any phase-, timing- or gain-differences caused by the cables themselves, so that these may be compensated for in the signal analysis. For this purpose the Coherence Unit Remote Control Software provides a calibration mode separate to the coherence measurement mode. The instrument connections required for the calibration mode are described in the following section.

Note: Measurements may also be performed without calibration, though this will result in lower accuracy of the estimated parameters and is not recommended.

3.1.1 Test setup for the calibration procedure

To perform a calibration the instruments should be connected as shown in Figure 4. Make sure that both analyzers use the external reference clock supplied by the signal generator (select "*SETUP → REFERENCE FREQUENCY → REFERENCE EXTERNAL*" on both analyzers).

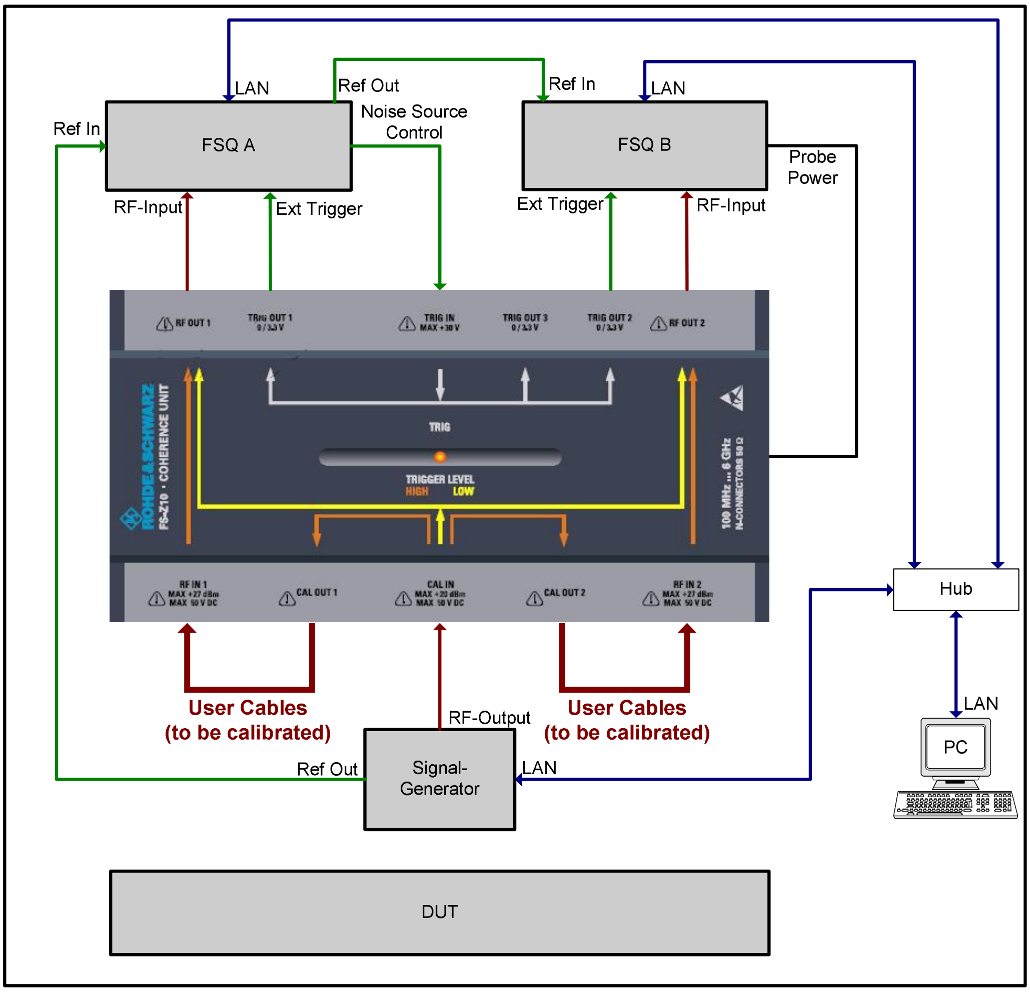


Figure 4: Cable Connections for the Calibration Mode

3.1.2 Cable calibration procedure

Once the devices have been connected correctly, the following steps may be used to perform the calibration:

1. Start the Coherence Unit remote software on your PC (“Start → Programs → R&S Coherence Control → R&S Coherence Control”).
2. Open the Settings Menu.

   Set the addresses of the connected analyzers in the “Hardware Settings”.

	Nr	State	VISA RSC	Device
▶	1	Master	TCPIP::10.114.11.75	A: FSG
	2		TCPIP::10.114.10.220	B: FSG
	3		TCPIP::10.114.11.26	SigGen: SMU

3. Configure the “Data Capture Settings” in the “Settings” menu according to the signals to be measured.

4. Press the “Calibrate” Key in the Hotkey-Bar.

If the calibration was successful the Calibration-display in the header-bar will switch from “UNCAL” to “CAL” and show the time at which the calibration was performed.

The color of the text indicates the quality of the calibration result. If the text is orange or red there might be problems in the test setup (in this case you should check your cables again and make sure that both analyzers are configured to use the external reference supplied by the signal generator). Green color stands for a good calibration result.

Figure 5: Good quality of the calibration result (green)

Figure 6: Poor quality of the calibration result (orange)

3.2 Performing the Coherence Measurement

For the actual coherence measurement the signal-differences which were measured during the cable calibration will be compensated automatically by the software. If no calibration has been performed the software will assume that cables with identical characteristics are being used.

3.2.1 Test setup for the coherence measurement

In order to perform a coherence measurement connect the devices as shown in Figure 7 and make sure that both analyzers use the external reference clock supplied by the signal generator (select “*SETUP → REFERENCE FREQUENCY → REFERENCE EXTERNAL*” on both analyzers).

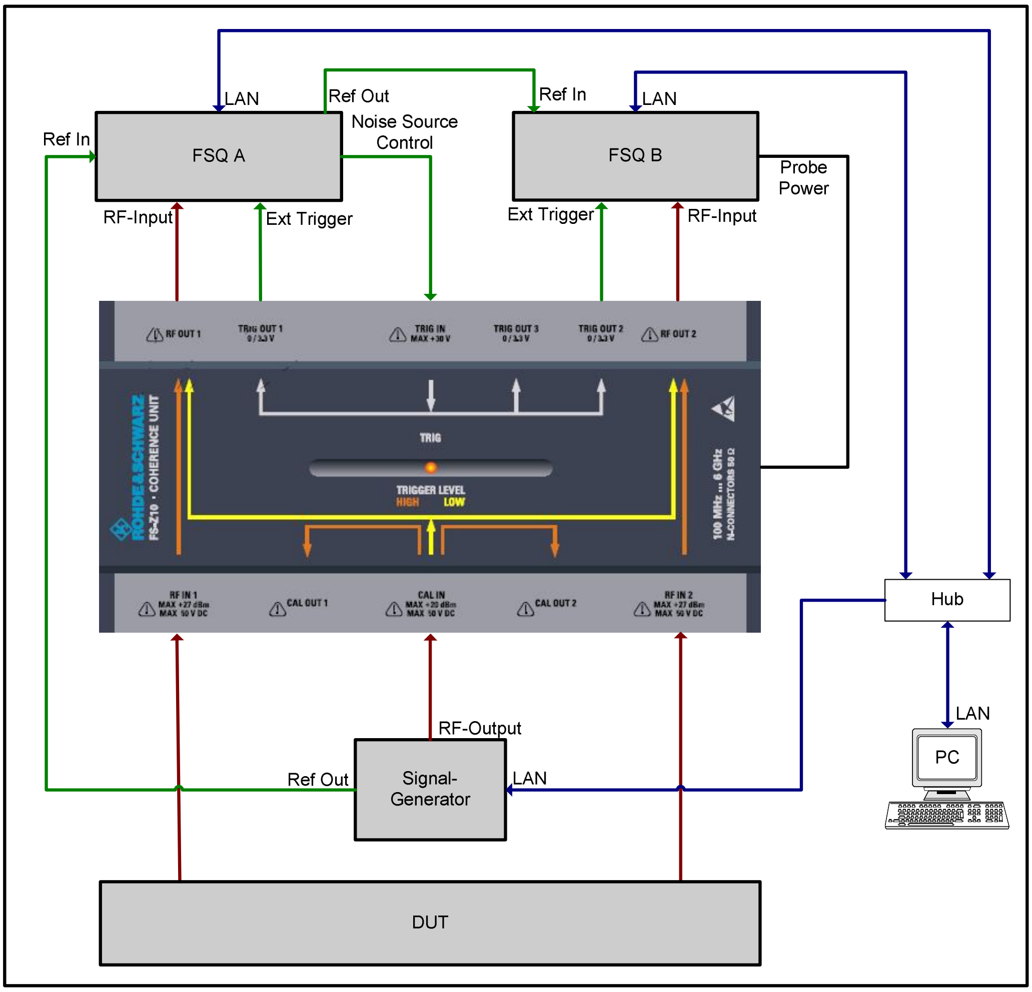


Figure 7: Cable connections for Measurement Mode

3.2.2 Coherence measurement procedure

Once the devices have been connected correctly, the following steps may be used to perform the coherence measurement:

1. Start the Coherence Unit remote software on your PC ("Start → Programs → R&S Coherence Control → R&S Coherence Control")
2. Open the Settings Menu.

   Set the addresses of the connected analyzers in the "Hardware Settings".

	Nr	State	VISA RSC	Device
▶	1	Master	TCPIP::10.114.11.75	A: FSG
	2		TCPIP::10.114.10.220	B: FSG
	3		TCPIP::10.114.11.26	SigGen: SMU

3. Configure the "Data Capture Settings" in the "Settings" menu according to the signals to be measured.

4. Press the “RUN SGL” button for a single measurement or the “RUN CONT” button for continuous measurements.
5. View the measurement results in graph or result list mode (switch views via the “Display”-softkey).

3.2.3 Improving the Measurement Accuracy

3.2.3.1 Activating the High Accuracy Mode

The Coherence Unit Software provides the opportunity to use an optional High Accuracy Mode. This mode takes hardware characteristics of a specific FS-Z10 into account and therefore leads to improved overall accuracy of the results. The properties of your specific device can be found in the form of a “.dat”-file which can be downloaded from the Rohde&Schwarz website (see chapter 3.2.3.2).

To activate the High Accuracy Mode choose “Setup → Select High Accuracy File” in the Coherence Unit Control Software and select the file corresponding to the serial number of your Coherence Unit. On success the “High Accuracy Mode”-entry of the header will show the serial number and the service number of your coherence unit.

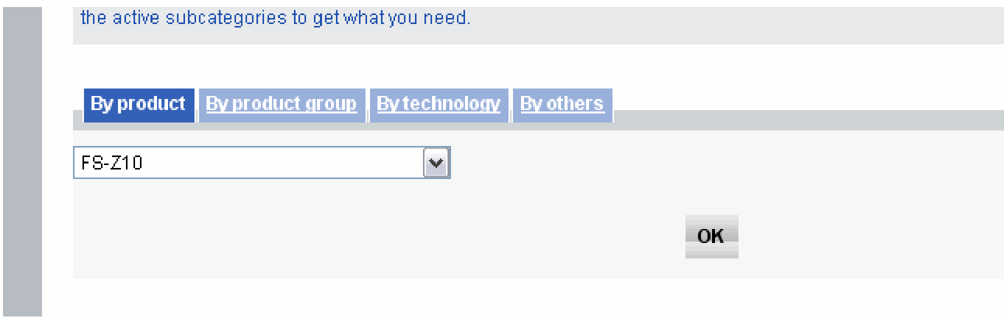
3.2.3.2 Obtain up-to-date High Accuracy Files

The high accuracy files are specific for each coherence unit. In order to download a new high-accuracy-file for your specific device perform the following steps (internet access is required):

1. Open a browser and go to:
   www.rohde-schwarz.com

2. Select “Service & Support”

3. Select “Download Search”
4. Select the FS-Z10 in the product selection box an press OK



5. Select “Device Specific Data” and press OK
6. Click on the high-accuracy data link

Device Specific Data

Description	Last Modified
High Accuracy Calibration Data for R&S®FS-Z10	

7. Enter the device specific serial number of your coherence unit

High Accuracy Calibration Data for R&S®FS-Z10

Device Specific Download Request

Serial No. 100008

Start Download

Make sure to keep your high accuracy file up-to-date. A new file is needed each time your coherence unit has been serviced by Rohde & Schwarz.

4 Explanation of the Results

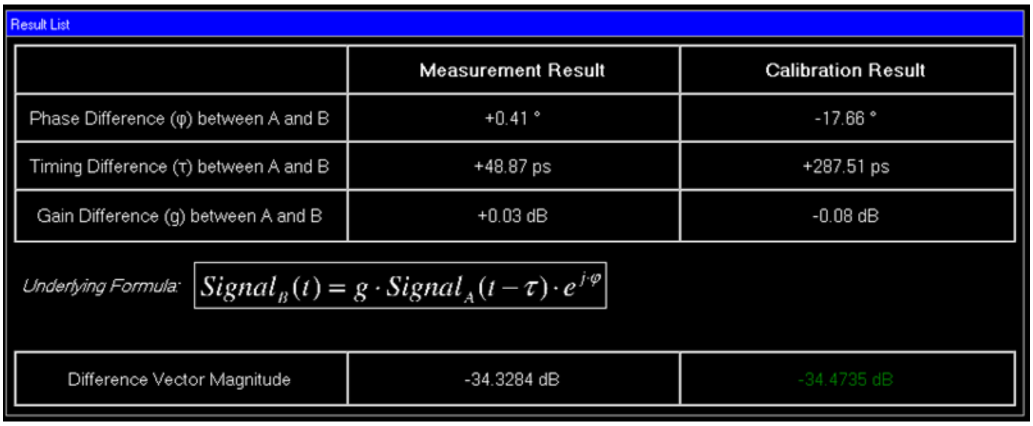
4.1.1 Result Overview

Figure 8: Result Overview

The result overview provides a summary of the most relevant measurement settings and results. The following values are displayed:

Value	Description
1. Frequency	Displays the currently selected centre frequency for both analyzers.
2. Sample Rate	Displays the currently selected sample rate for both analyzers.
3. High Accuracy Mode	Indicates if the software is currently running in high accuracy mode (see chapter 3.2.3).
4. Ref Level(A|B)	Displays the current reference levels of both analyzers (analyzer A and analyzer B).
5. Capture Length	Displays the currently selected capture length in seconds and in samples.
6. High Accuracy Service No	Displays the high accuracy service number of the currently selected high accuracy file (see chapter 3.2.3).
7. Calibration Status	Displays the current calibration state (see chapter 3.1).
8. Measurement DVM	Displays the current Difference Vector Magnitude (see chapter 4.1.2).
9. Serial Number	Displays the serial number of the currently selected high accuracy file. If you are running the software in high accuracy mode this number must be identical to the serial number of your Coherence Unit.

4.1.2 Result List



Result List

	Measurement Result	Calibration Result
Phase Difference (φ) between A and B	+0.41 °	-17.66 °
Timing Difference (τ) between A and B	+48.87 ps	+287.51 ps
Gain Difference (g) between A and B	+0.03 dB	-0.08 dB

Underlying Formula: $Signal_B(t) = g \cdot Signal_A(t-\tau) \cdot e^{j \cdot \varphi}$

Difference Vector Magnitude	-34.3284 dB	-34.4735 dB

Figure 9: Result List

The right-most column of the table in Figure 9 shows the results of the calibration, while the column to the left shows the measurement results for the DUT. The three parameters; φ (=phase difference), τ (=timing difference) and *g* (=gain difference), describe the coherence of Signal A and Signal B with respect to the following formula:

$$s_B(t) = g \cdot s_A(t-\tau) \cdot e^{j \cdot \varphi}$$

The Difference Vector Magnitude (DVM) is an indicator for checking the accuracy of the results. The DVM is calculated by comparing Signal A ($s_A(t)$) with the compensated Signal B ($\tilde{s}_B(t)$) using the following formula:

$$DVM = 10 \cdot \log_{10}\left(\frac{\sum_t \left|\tilde{s}_B(t) - s_A(t)\right|^2}{\sum_t \left|s_A(t)\right|^2}\right)$$

A lower DVM indicates a better measurement accuracy.

4.1.3 Long Term Measurement Results

In some cases it might be useful to watch the changes of the signal differences over a certain period of time. For this purpose the Coherence Software provides a log file that automatically stores the results of continuous measurements. The file will be stored under ***"<Program Folder>\Logfile.txt"*** and contains information about every sweep since the last continuous measurement has been started (press the “RUN CONT”-button to start a continuous measurement).

Note: The log file is overwritten whenever a new continuous measurement is started.

```
#     Sweep started at 29.01.2009 14:20:22
#     Format: Phase-offset[°]|Time-offset[s]|Gain-offset[dB]|Difference Vector Magnitude|Time of day|Date

+0.0967|-3.04721295833588E-11|+0.0008|-32.37|14:20:37|29.01.2009
+0.0014|+1.46384816616774E-11|+0.0039|-32.44|14:20:40|29.01.2009
+0.1190|-6.38663768768311E-12|+0.0011|-32.41|14:20:44|29.01.2009
-0.0798|-3.91304492950439E-11|+0.0050|-32.44|14:20:47|29.01.2009
-0.1628|+2.4472177028656E-11|+0.0007|-32.40|14:20:51|29.01.2009
+0.1090|+2.91481614112854E-11|+0.0004|-32.37|14:20:55|29.01.2009
+0.0111|+1.39757990837097E-11|+0.0021|-32.43|14:20:58|29.01.2009
+0.1576|+2.96264886856079E-11|+0.0064|-32.33|14:21:02|29.01.2009
-0.0171|-8.24034214019775E-12|+0.0014|-32.41|14:21:05|29.01.2009
-0.0726|+3.81380319595337E-11|+0.0064|-32.40|14:21:09|29.01.2009
-0.0423|-1.935213804245E-11|+0.0008|-32.46|14:21:12|29.01.2009
-0.0439|-1.16020441055298E-11|+0.0012|-32.43|14:21:16|29.01.2009
+0.2550|+2.08377838134766E-11|+0.0021|-32.36|14:21:19|29.01.2009
+0.1130|-5.61624765396118E-11|-0.0057|-32.37|14:21:23|29.01.2009
+0.1856|+1.69237260706723E-11|+0.0040|-32.39|14:21:26|29.01.2009
```

Figure 10: Log file for continuous mode

4.1.4 Compensation of the Signal Differences and storing the IQ-data

In addition to performing the coherence measurement, the Coherence Unit remote software also offers the possibility to store the captured IQ-data to file. The IQ-data may also be compensated in different ways before it is stored. The choice as to which signal differences are to be compensated is available in the “Settings” menu.
Figure 12 and Figure 13 show the effect of the compensation on the capture buffer display:

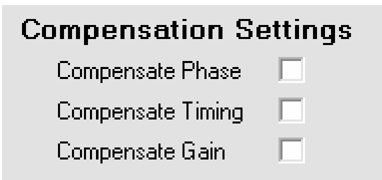


Figure 11: Compensation settings in the settings menu.

Note: Changes to compensation settings are not applied until the refresh button in the main window is pressed or a new sweep has been performed.

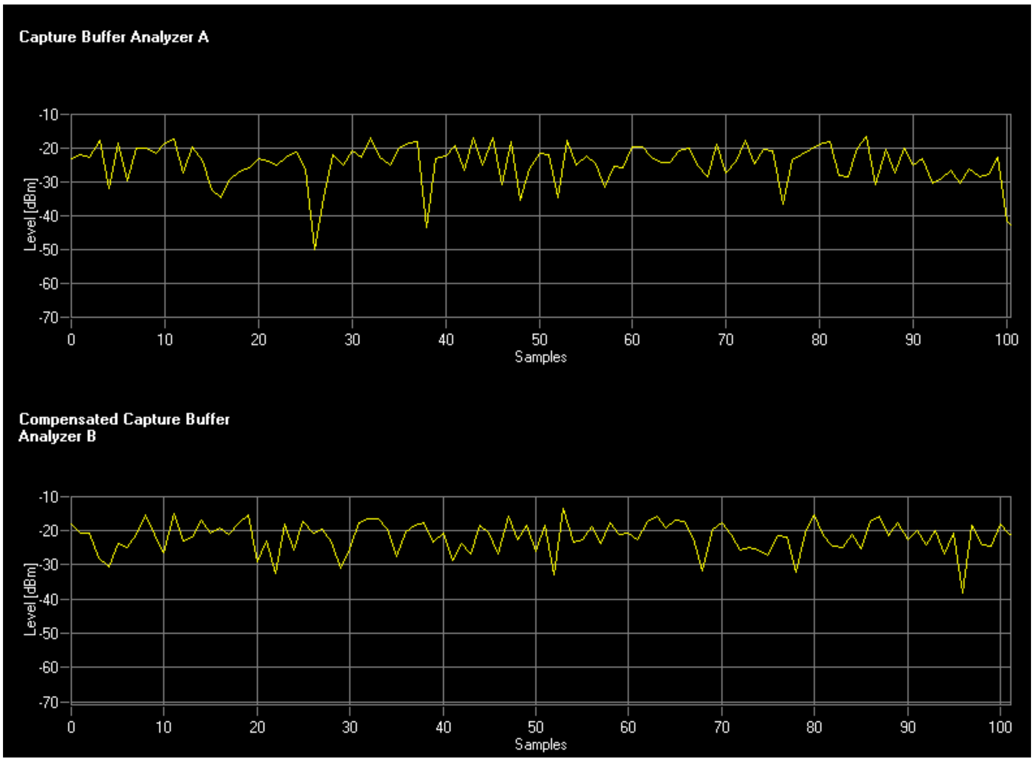


Figure 12: Capture buffer A and B without any compensation activated.

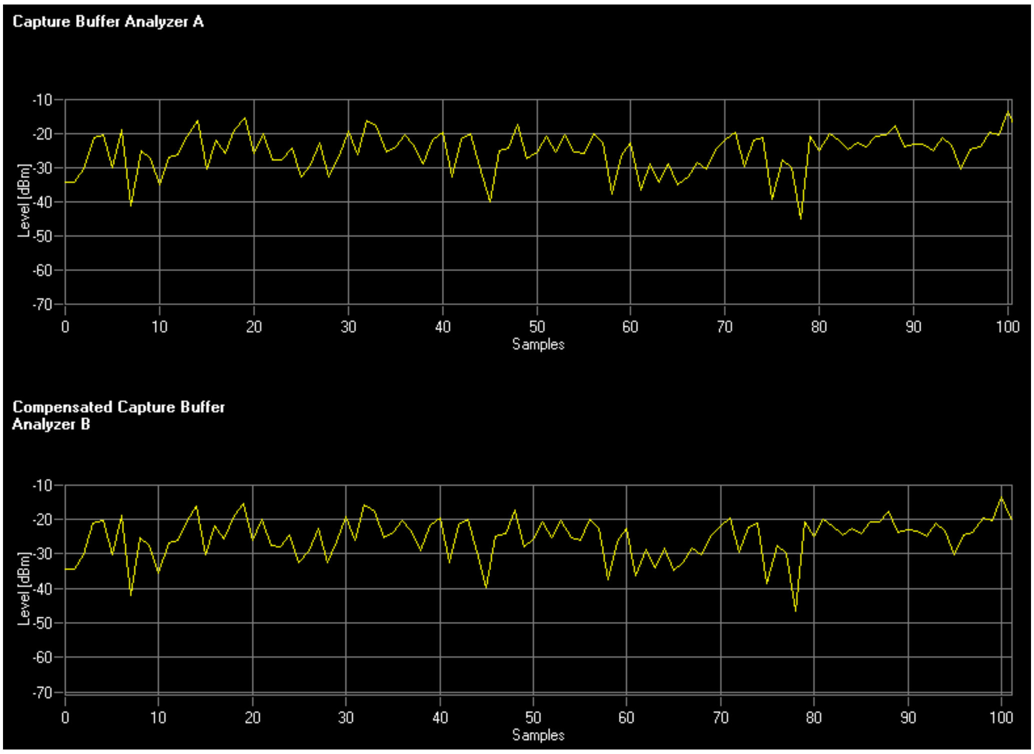


Figure 13: Capture buffer A and B with compensation of all coherence parameters.

The compensation settings only refer to the signal differences caused by the device under test. Signal differences due to the testing environment (see section **Fehler! Verweisquelle konnte nicht gefunden werden.**) will always be compensated automatically. The cable parameters will always be compensated if a calibration has been previously performed (see chapter 3.1).
Press the "Save as"-button to store the current IQ-data to file. Three different data types can be selected in the file dialog.

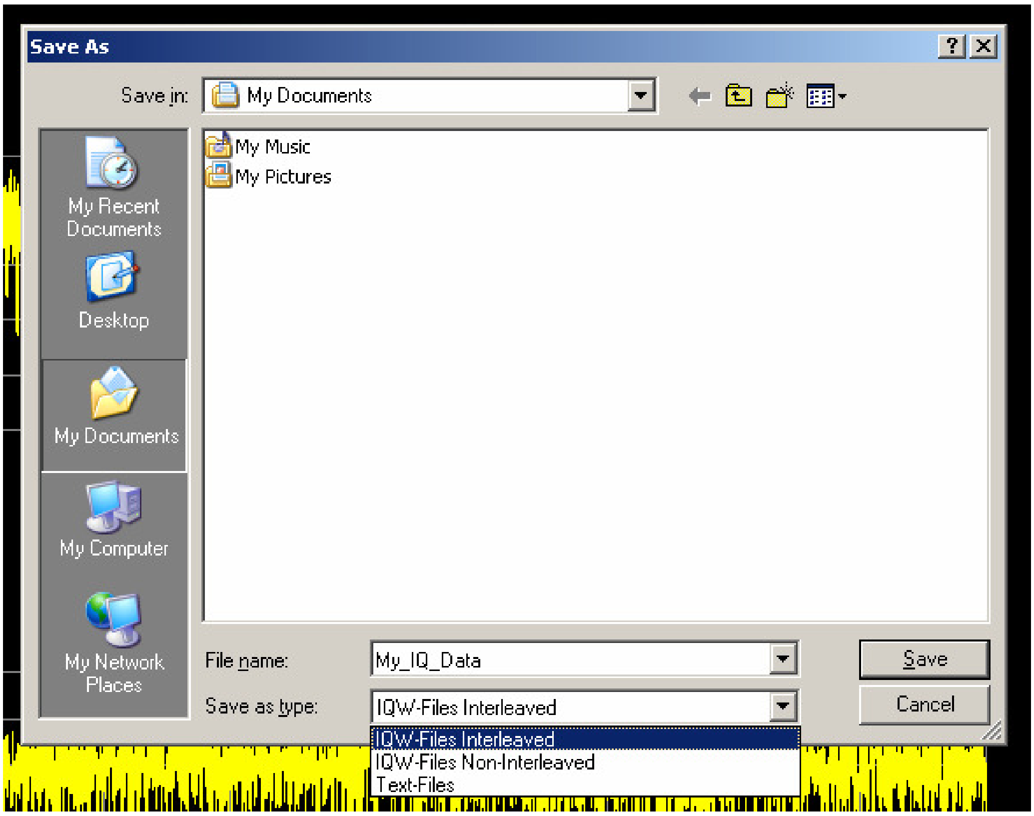


Figure 14: File dialog for saving IQ-data

After confirming the file name by pressing the "Save"-button two files will be created. One of them contains the IQ-data of capture buffer A and the other one contains the IQ-data of capture buffer B. The capture buffer identifier will be appended to the filenames automatically (e.g. "My_IQ_Data_A.iqw" and "My_IQ_Data_B.iqw").

5 Coherence Unit Remote Software

The process described in chapter 2.2.1 is controlled by the Coherence Unit remote software which is provided with the FS-Z10 hardware.

5.1 Software Features

This Software offers the following features:

- Coherent measurement of two RF-signals which determines phase, timing and gain differences.
- A calibration mode for measurement and compensation of the cables used to connect the device under test to the Coherence Unit.
- Compensation of the captured IQ-data with respect to time, phase or gain. The compensated data is saved to file and available for further analysis.
- A measurement result list and capture buffer graph (power versus time) of both RF-signals.
- Continuous mode for long term measurements including an automatically generated log file containing results and time stamps.
- Automatic configuration of the analyzers and the reference signal generator using the settings specified via a graphical user interface.

5.2 Requirements

5.2.1 PC Hardware Requirements

	Minimum	**Recommended**
RAM	1 GByte	2 GByte
Harddisc	15 MByte free space	50 MByte free space
Monitor	VGA monitor (640x480)	SVGA colour monitor, resolution 800x600 or better
IEEE Bus	Optional	Optional

5.2.2 PC Software Requirements

Operating System	Windows XP
VISA	Any

6 Conclusion

The Coherence Unit combined with the corresponding Remote Control software provides an easy and cost-efficient way to measure differences in phase, timing and gain between two radio frequency signals. Unwanted distortions (e.g. temperature changes of the cables) which could decrease the accuracy of such a measurement will be compensated for automatically using a reference signal. This approach allows calculation of signal differences resulting solely from the device under test. The software also provides the option to compensate the measured signal differences and save the IQ-data to file.

7 Additional Information

Please send any comments or suggestions about this application note to **TM-Applications@rsd.rohde-schwarz.com**.

8 Ordering Information

Type of instrument	
FS-Z10	1171.6509.02

Please note, that complete solutions for field strength and power measurements for various applications are available from Rohde & Schwarz.
For additional information about antennas, receivers, spectrum analysers and field strength measurement equipment, see the Rohde & Schwarz website www.rohde-schwarz.com.

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, radio monitoring and radiolocation, as well as secure communications. Established 75 years ago, Rohde & Schwarz has a global presence and a dedicated service network in over 70 countries. Company headquarters are in Munich, Germany.

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