

R&S®FSW-K70

Measuring the BER and the EVM for Signals with Low SNR

Application Sheet

Signals with low signal-to-noise ratios (SNR) often cause bit errors during demodulation, so that modulation accuracy values such as the error vector magnitude (EVM) may not be determined correctly.

This application sheet describes:

- The significance of the Bit Error Rate (BER) parameter for signal analysis
- How the R&S FSW VSA application calculates the BER and determines bit errors
- How this knowledge can be used to obtain correct modulation accuracy results



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1 Introduction

What is the Bit Error Rate (BER)?

In signal analysis, a bit error occurs when a false symbol decision is made during demodulation. That is: the demodulated symbol does not correspond to the transmitted symbol. Bit errors often occur when demodulating highly distorted signals or signals with low signal-to-noise ratios (SNR).

Bit errors due to noise cause additional points in a constellation diagram, creating a "cloud" around the ideal symbol point. If these points exceed the defined symbol decision boundaries for the symbol mapping of the used modulation, wrong symbol decisions are made and the number of bit errors increases.

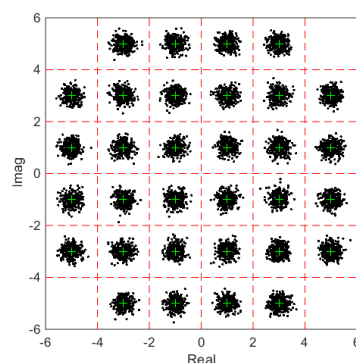


Figure 1-1: Constellation diagram with "clouds" of bit errors caused by noise

The bit error rate (BER) is calculated by comparing the transmitted bits with the determined symbol decision bits in the measured signal. The number of falsely detected bits is then set in relation to the total number of analyzed bits:

$BER = \text{falsely detected bits} / \text{number of analyzed bits}$

How do you detect bit errors in the signal and calculate the bit error rate?

Obviously, knowledge of the originally transmitted data is required. There are two possible methods of calculating the bit error rate:

- **With a signal generator:** The data transmitted to the DUT by the signal generator is also sent to a BER calculator. The measured, demodulated data from the analyzer is also sent to the BER calculator. The BER calculator can then compare the data and provide the results.

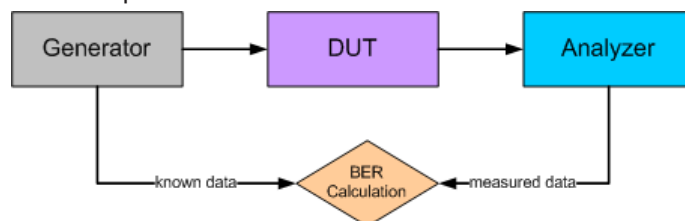


Figure 1-2: BER measurement using the signal generator data

- **Without a signal generator:** The information on the expected input signal is provided to the analyzer in advance. The analyzer then compares the measured, demodulated data with the available reference information and can calculate the BER itself.

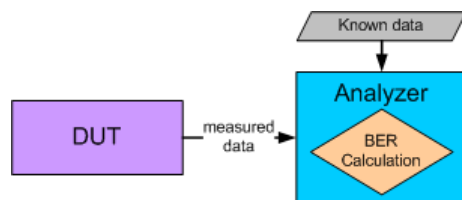


Figure 1-3: BER measurement without a generator, using the R&S FSW VSA application

If knowledge of the expected input signal is available, the R&S FSW VSA application provides BER results without the need of connecting a signal generator. The required information consists of a set of all possible data sequences of the input signal. These data sequences are stored in a *Known Data file* in a predefined format, and then loaded in the R&S FSW VSA application.

2 How to Create Known Data Files

The R&S FSW VSA application provides an auxiliary tool on the R&S FSW (free of charge) to create Known Data files from existing data. You can copy this tool to a PC and work with it locally, as well.

This section describes how to create known data files using this tool.



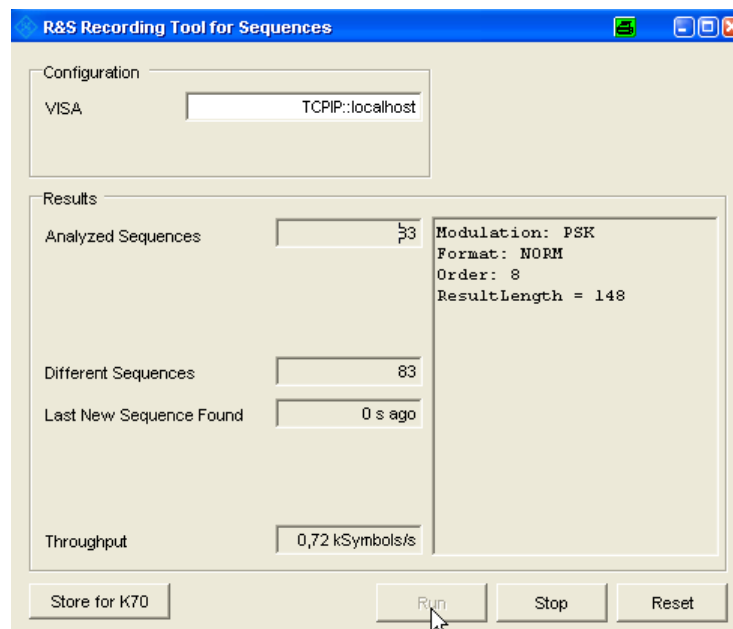
It is essential that **no bit errors occur during this recording**. To obtain stable results before recording known data sequences refer to [Tips for Improving Signal Demodulation in Preparation for the Known Data File](#).

If it is not possible to ensure stable demodulation in order to record known data sequences, you can also create the Known Data files yourself. Use any XML editing tool you like, following the rules of the syntax defined by Rohde & Schwarz (see the R&S FSW VSA application user manual). Before loading the file to the R&S FSW VSA application, make sure the syntax of your file is valid.

To create a Known Data file using the recording tool for sequences

1. Import or input data for which stable demodulation results are available to the R&S FSW VSA application. If necessary, adapt the demodulation settings until the requested results are obtained (see [Tips for Improving Signal Demodulation in Preparation for the Known Data File](#)).
2. Do one of the following:
 - Start the "R&S Recording Tool for Sequences" from the Windows task bar on the R&S FSW.
 - Execute the file
`C:\Program Files (x86)\Rohde-Schwarz\FSW\<version>\RecordingToolforSequences.EXE` on the R&S FSW.

The "R&S Recording Tool for Sequences" window is displayed.



3. Define the VISA resource string required to connect to the instrument:
 - If the tool is started directly from the instrument: enter `TCPIP::localhost` (default).

- If the tool is started from a computer: enter the TCPIP address or name of the computer in the VISA resource string (e.g. TCPIP: :123.4.5.6).
4. In the tool window, select "Run".
- The tool records the demodulated data sequences. The following result information is provided by the tool during recording:
- **Analyzed Sequences:** number of data sequences analyzed since the tool was started
 - **Different Sequences:** number of unique sequences detected in the measured data
 - **Last New Sequence Found:** time that has passed since the most recent unique sequence was detected
 - **Throughput:** current data processing speed of the tool

Note that while the tool is running, the R&S FSW is set to remote mode, that is: the manual interface is not available. As soon as the tool is closed, the remote mode is automatically deactivated.

Tip: Sometimes the recording tool window is moved to the background and is no longer visible behind the R&S FSW firmware window.

In this case, select the on-screen keyboard key, then press the "Windows" key twice. Select the tool icon in the task bar to bring it back to the foreground.



Figure 2-1: On-screen keyboard key

5. Stop the tool by selecting "Stop" when one of the following situations occurs:
- All known possible sequences have been detected
 - A significant amount of time has passed to assume no more sequences will be detected
6. • If the results are acceptable, select "Store for K70" to store a valid XML file with the recorded data sequences.
A file selection dialog box is displayed in which you can select the storage location and file name.
You can also add an optional comment to the file.
- Otherwise, reset the tool to start a new recording, possibly after changing the demodulation settings or input data.
7. Close the tool window to return to normal operation of the R&S FSW VSA application.

The created XML file can now be loaded in the R&S FSW VSA application.

3 BER Measurement in the R&S FSW VSA application

Imagine an input signal with a low signal-to-noise ratio, where the burst does not rise out of the noise significantly.

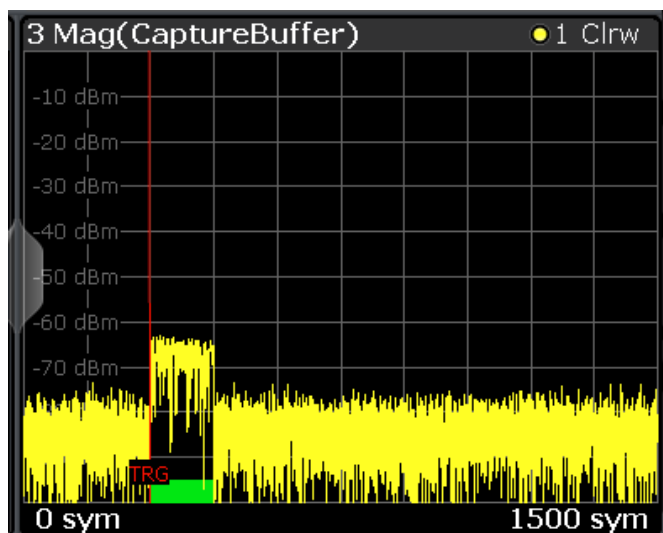


Figure 3-1: Example of a signal with a low signal-to-noise ratio

The error vector magnitude (EVM) display for this signal shows a distinct spike (see Figure 3-2). Such spikes, especially in poor signals, often indicate a problem and should be analyzed more closely. Possibly a transmitted bit was distorted by noise, causing a false symbol decision during demodulation by the R&S FSW VSA application.

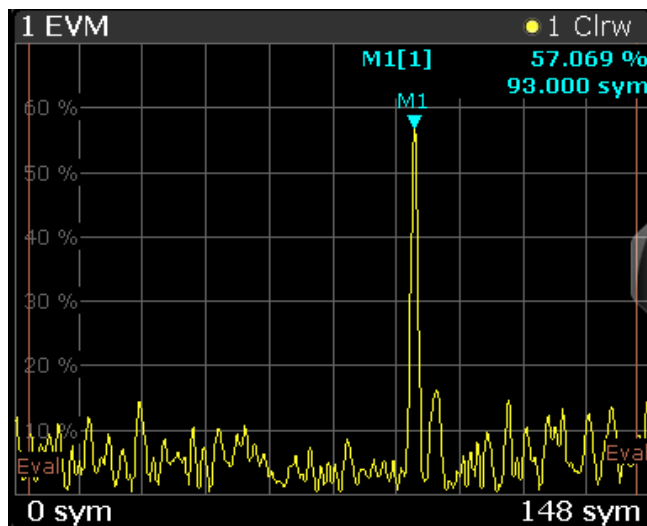


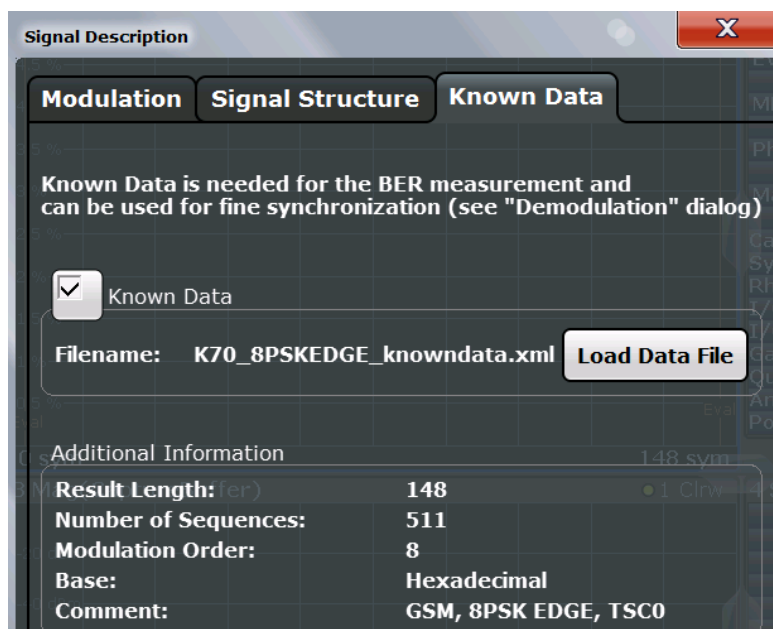
Figure 3-2: EVM for the signal with a spike, presumably due to a symbol decision error

If only the detected data is available from which the R&S FSW VSA application can estimate a reference signal, the reference signal is not correct due to the false symbol decision. Then *all results based on the reference signal*, and thus also the EVM, are *false!*

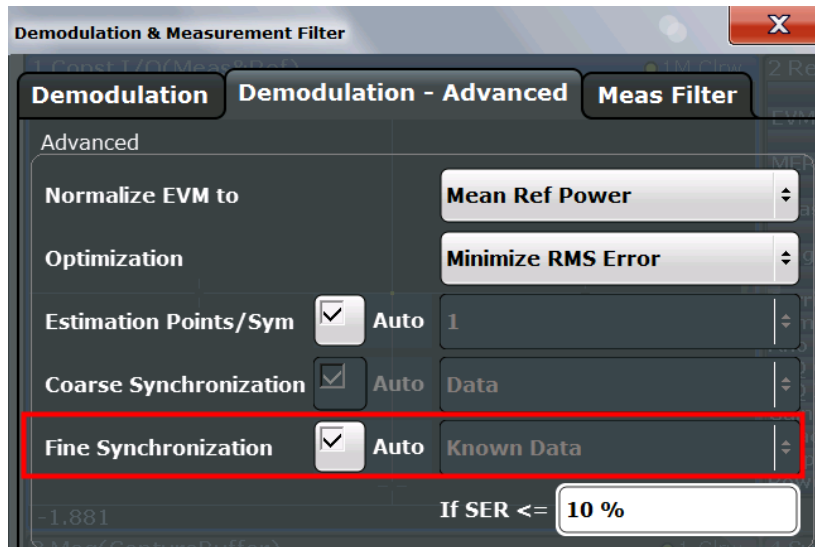
Therefore, particularly for signals with high distortion or low signal-to-noise rates, it is important that you make sure no bit errors have occurred. The BER measurement is a useful way to check that.

If a Known Data file exists for the input signal, the R&S FSW VSA application can create the reference signal from the bit sequences in the known data file. Using this knowledge, the R&S FSW VSA application can not only calculate the results correctly, it can also calculate the BER.

For our sample signal above, a Known Data file is loaded to the R&S FSW VSA application.



Due to the default setting for "Fine Synchronization", the reference signal is automatically generated from the known data as soon as the file is loaded in the R&S FSW VSA application. (See the R&S FSW VSA application user manual for details on synchronization).



Using the correct reference signal, the results - in particular the EVM - are calculated accurately, and the Bit Error Rate result display becomes available.

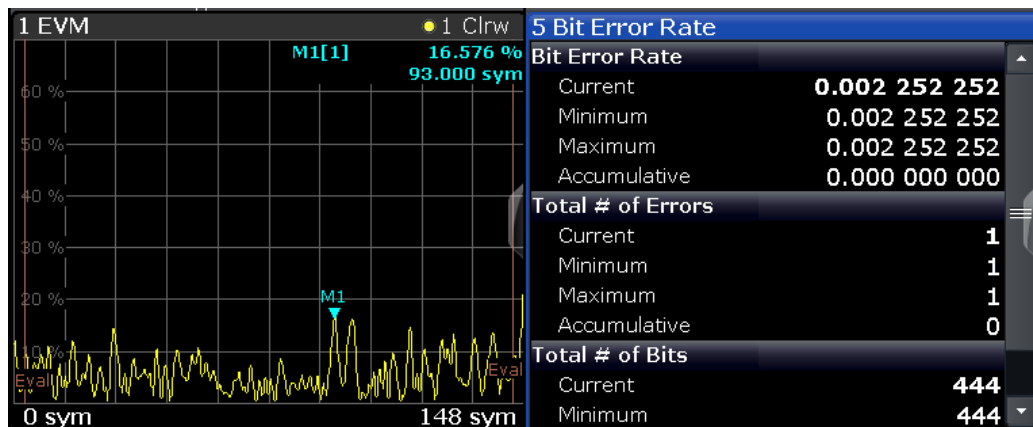


Figure 3-3: EVM and BER for the same signal using a known data file for synchronization

In the example described above, our assumption is proven to be correct: a bit error has occurred. However, the EVM diagram no longer contains the distinct spike (see Figure 3-3). Using known data, the R&S FSW VSA application is able to measure correctly, despite the low signal-to-noise ratio of the input signal.

4 Tips for Improving Signal Demodulation in Preparation for the Known Data File

In order to create a Known Data file from a measurement in the R&S FSW VSA application, it is essential to provide stable, correctly demodulated measurement results. As a rule of thumb, if the average EVM for the input signal is more than 5 %, try to

improve the results before creating a Known Data file. (Obviously, this value depends strongly on the type of modulation used.)

This chapter describes which parameters of the measurement configuration influence demodulation and how it can be improved.

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4.1 Burst Search

If a signal is bursted, only the bursts contain relevant information. It is essential to limit the internal analysis to the actual bursts, that is: those areas in which the burst power is up. If burst search is activated, the signal is searched for bursts according to predefined burst definitions. Further calculation can then be restricted to the detected bursts only.

However, in signals with a low signal-to-noise ratio, it may be difficult to determine where a burst starts and stops. Obviously, the definitions must be as accurate as possible, to ensure a robust burst detection. Burst searches include the following parameters:

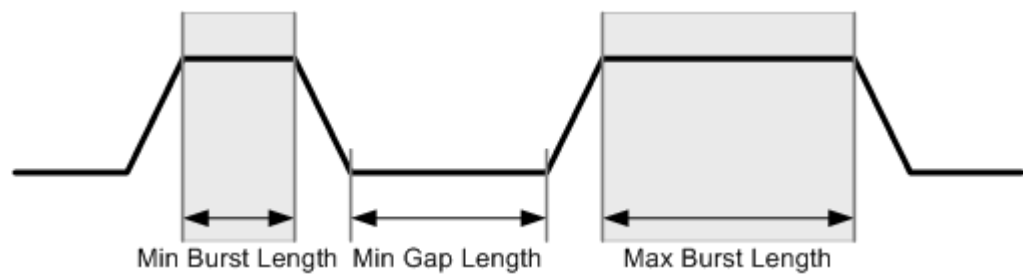


Figure 4-1: Burst Search parameters

- Minimum and maximum burst length

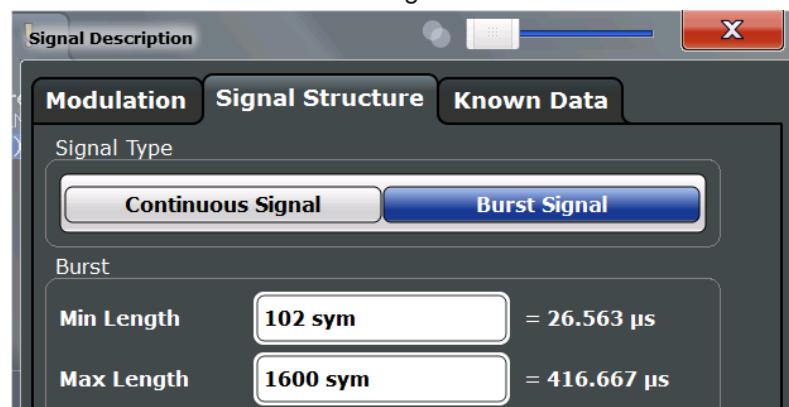


Figure 4-2: Burst length configuration

- "Search tolerance"
Defines how tolerant the burst search is when comparing the burst length in the measured signal to the defined values
To be detected, bursts must have a length between ("Min Burst Length" – "Search Tolerance") and ("Max Burst Length" + "Search Tolerance").
- "Minimum gap length"
A minimum gap must be found between two successive bursts.
Increase the minimum gap length to enhance the robustness of the burst search if the following conditions apply:
 - The signal is highly distorted and/or has modulation noise
 - The bursts within your capture buffer are not closely spaced
- "Meas only if Burst found"
Demodulation is only performed on detected bursts

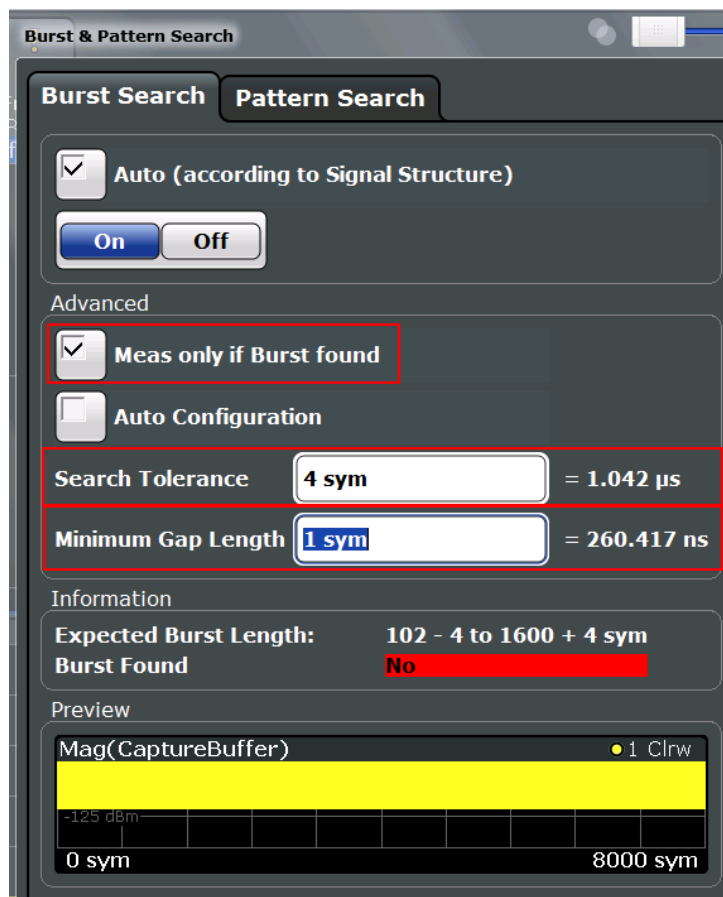


Figure 4-3: Burst gap and search settings



To make sure a burst is found in the current measurement signal using the current settings, check the "Information" provided in the "Burst Search" dialog box.

4.2 Pattern Search

If the burst search fails due to high distortion or low SNR, a pattern search can be more robust. During the I/Q pattern search, the capture buffer is searched for a pre-defined I/Q pattern. An I/Q pattern is considered detected if the correlation metric, that is: the correlation value between the ideal I/Q pattern and the capture buffer, exceeds a specified "I/Q Correlation Threshold".

If the signal is so distorted that even the pattern search fails, try reducing the "I/Q Correlation Threshold" (see [Figure 4-4](#)).

For very short patterns, that is: a pattern length in the order of the inter-symbol interference (ISI) duration, "false positives" and "false negatives" can occur. A "false positive" means the I/Q pattern is found at positions where the transmitted symbols differ from the pattern symbols. A "false negative" means the I/Q pattern search missed a position where transmitted symbols do match the pattern symbols. Adjusting the "I/Q Correlation Threshold" can help avoid both cases.

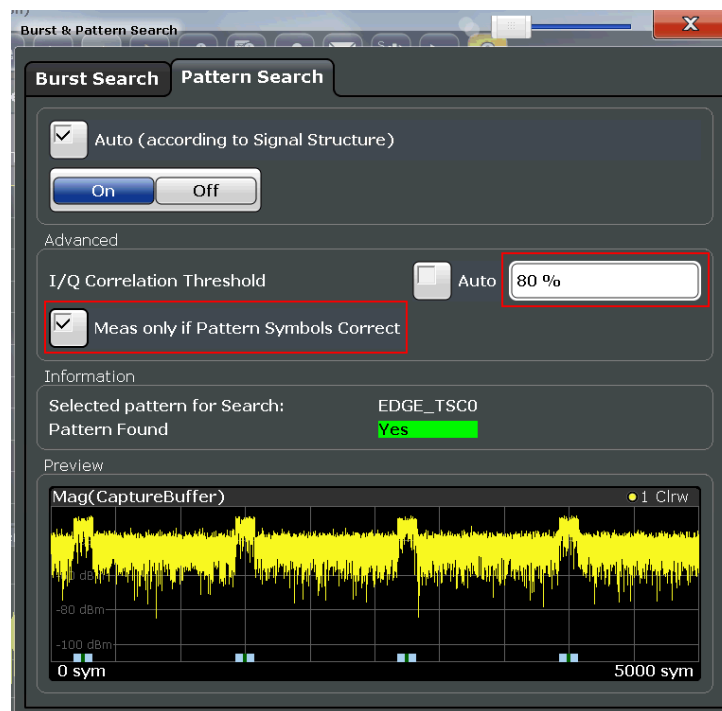


Figure 4-4: I/Q correlation threshold and restricting the measurement to detected patterns

After the pattern search, the result range is aligned to the pattern. The R&S FSW VSA application demodulates the measured signal within the result range, and checks the transmitted symbols for correctness against the pattern symbol sequence.

Similarly to restricting demodulation to detected bursts, the measurement can also be restricted to correctly detected symbol patterns ("Meas only if Pattern Symbols Correct" in "Pattern Search" dialog box). This setting increases the accuracy of the results.

Check the information provided in the "Pattern Search" dialog box to make sure a pattern is detected in the current measurement signal using the current settings.

4.3 Equalization Mode

A possible source of high modulation errors of the DUT with PSK and QAM signals is a non-flat frequency response or ripple in frequency response within the modulation bandwidth. An equalizer filter with a reverse frequency response characteristic can compensate less-distorted frequency responses to improve the modulation analysis results.

For more complex distortions, the reference signal might not be determined correctly due to wrong symbol decisions. Despite the resulting imperfect equalizer calculation, the estimated equalizer is often good enough to improve the reference signal creation in the succeeding sweep. Thus, the new equalizer is improved successively. This processing mode of the equalizer is called **tracking mode**. After only a few sweeps, the results are sufficiently accurate and the learning phase is completed. Then the equalizer can be used without additional calculations as long as the input signal remains stable.

If the result range used for equalizer calculation is too short, the equalizer provides unstable impulse responses. For time-invariant channels, the estimation length can be extended using **Averaging mode**. In this case, the statistics from *all* previously determined reference signals and measurement signals are averaged to determine the current equalizer function. Thus, the results of previous sweeps are continuously considered to calculate the current equalizer values. Obviously, this method requires a stable input signal for the entire duration of the measurement, as otherwise previous results distort the current equalizer.

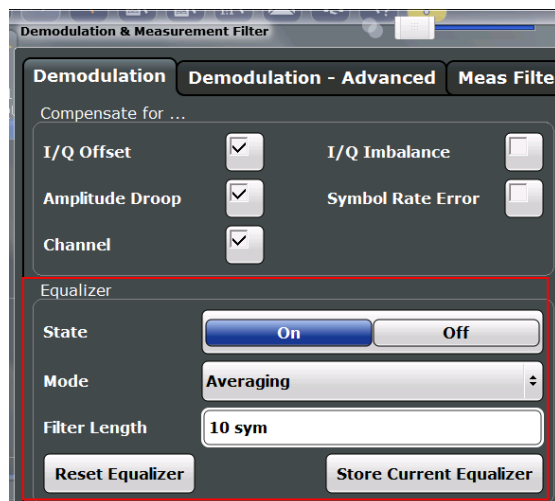


Figure 4-5: Configuring the equalizer

Filter length

The length of the equalizer can be defined in symbols. The longer the equalizer the higher the resolution in the frequency domain is and the more distortion can be compensated. The shorter the filter length, the less calculation time the analyzer requires during the tracking or averaging phase.

4.4 Symbol Rate Error Correction

If the specified symbol rate in the Signal Description dialog does not match the actual symbol rate of the transmitter exactly, the EVM typically displays a droop in the center of the burst (see [Figure 4-6](#)).

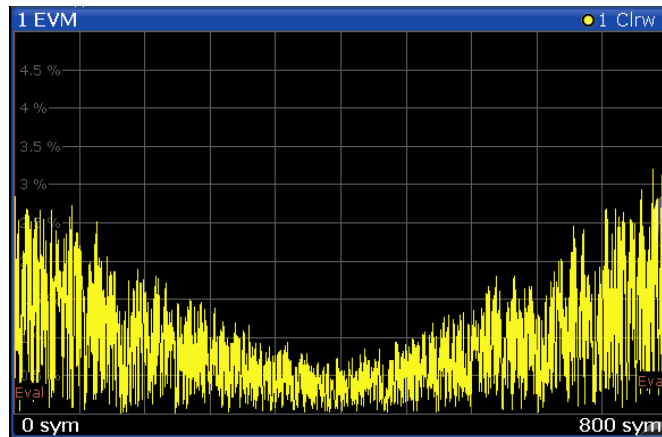
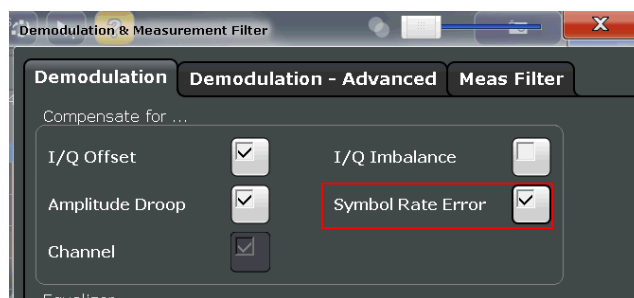


Figure 4-6: Typical EVM trace for a symbol rate error

To improve the EVM, enable compensation for the symbol rate error in the "Demodulation" settings.



The R&S FSW VSA application considers the detected symbol rate error during demodulation and corrects the measurement signal accordingly. The EVM trace no longer shows a droop (see [Figure 4-7](#)).

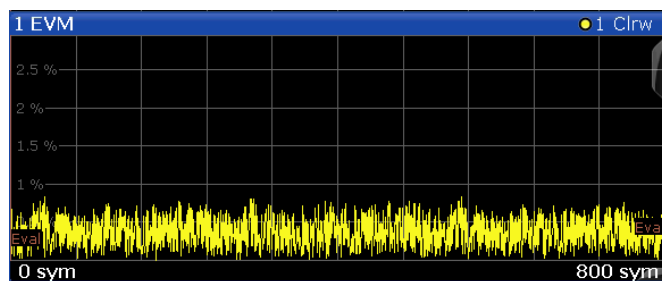


Figure 4-7: EVM trace with a corrected symbol rate error

5 Measurement Example - Measuring the BER

The following procedures describe the basic steps to create a known data file from a measurement on the R&S FSW, and perform a BER measurement in the R&S FSW VSA application.

The following input signal is assumed for this example:

Table 5-1: Transmitter Settings for the Measurement Example

Standard	GSM EDGE_8PSK
Center frequency	1 GHz
Level	0 dBm

To create a Known Data file using the recording tool for sequences

1. On the R&S FSW, press the MODE key and select the "VSA" application.
2. Open the "Overview" and select "Digital Standards".
3. Select the settings file:
`C:\R_S\INSTR\USER\vsa\Standards\GSM\EDGE_8PSK.xml` and then "Load".
 The instrument is adjusted to the stored settings for the selected standard and a measurement is started immediately.
4. Press the FREQ key and enter the "Center Frequency": *1 GHz*.
5. Check the EVM results of the measurement. If necessary, adapt the demodulation settings to improve the results (see [Tips for Improving Signal Demodulation in Preparation for the Known Data File](#)).
6. When the results are stable, press the RUN SINGLE key to stop the continuous measurement mode.
7. Do one of the following:
 - Start the "R&S Recording Tool for Sequences" from the Windows task bar on the R&S FSW.
 - Execute the file
`C:\Program Files (x86)\Rohde-Schwarz\FSW<version>\RecordingToolforSequences.EXE` on the R&S FSW.
 The "R&S Recording Tool for Sequences" window is displayed.
8. If the tool is started directly from the instrument, the default VISA resource string to connect to the instrument (`TCPIP::localhost`) can be used. Otherwise, enter the TCPIP address or name of the computer in the VISA resource string.
9. Switch to the R&S FSW VSA application and press the RUN SINGLE key to stop the continuous measurement mode.

10. In the tool window, select "Run".
The tool records the demodulated data sequences.
Tip: If the recording tool window is moved to the background and is no longer visible behind the R&S FSW firmware window, select the on-screen keyboard key, then press the "Windows" key twice. The tool window is brought back to the foreground.
11. Stop the tool by selecting "Stop" when one of the following situations occurs:
 - All known possible sequences have been detected
 - A significant amount of time has passed to assume no more sequences will be detected
12. Store the XML file with the detected sequences:
 - a) Select "Store for K70".
 - b) In the file selection dialog box, select the storage location and file name.
 - c) Select "Save" and close the tool window to return to normal operation of the R&S FSW VSA application.

To perform a BER measurement

1. In the R&S FSW VSA application, open the "Overview".
2. Select "Signal Description" > "Known Data".
3. Enable the "Known Data" option.
4. Select "Load Data File".
5. In the file selection dialog box, select the Known Data file name and then "Select".
6. From the "Overview", select "Display Config".
7. Add a new window or replace an existing one with the signal source "Modulation Accuracy".
8. Select "Window Config".
9. Select "Result Type": "Bit Error Rate".
10. Close the "Window Configuration" dialog box.

The Bit Error Rate is displayed.

4 Bit Error Rate			
	Current		Accumulative
Bit Error Rate	0.002 252 252		0.002 252 252
Total # of Errors	1		1
Total # of Bits	444		444



If the BER result is in the range of 0.5 or higher, presumably the required sequence is missing in the Known Data file. Make sure the selected file contains all possible data sequences. If necessary, create a new Known Data file as described in ["To create a Known Data file using the recording tool for sequences"](#) on page 14.

6 Additional Information

For a comprehensive description of the R&S FSW VSA application functionality, refer to the R&S FSW VSA application user manual. The user manual is available for download at the Rohde & Schwarz product site:

<http://www.rohde-schwarz.com/product/FSWK70.html> > Downloads > Manuals

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