Advanced Techniques for Spurious Measurements with R&S FSW-K50
White Paper

Products:

- R&S®FSW
- R&S®FSW-K50

Spurious emission search with spectrum analyzers is one of the most demanding measurements in the design, verification and production of RF and microwave devices. RF designers, especially in the aerospace & defense industry need to detect very low level spurs. Very narrow resolution bandwidths are required to achieve the low noise required for these measurements, which increases measurement time. Even working with very fast spectrum analyzers, a spur search may take several hours or even days.

In this paper we will review the basics of spurious measurements and how the parameters used can affect the detection performance. A new technique as used in the R&S®FSW-K50 spurious measurement application which makes spurious search faster and easier to configure.

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1 Introduction

Spurious emissions are unwanted emissions inside and outside the necessary signal bandwidth; they can be caused by harmonic emissions, parasitic emissions, intermodulation and frequency conversion products.

Spurious emissions decrease the system performance and cause interference with other systems working in adjacent frequency bands or with other modules within the equipment.

Figure 1 Changes in I/Q Constellations diagram of a 64 QAM modulated signal with increasing interference

Spurious emission search with spectrum analyzers is an essential measurement in the design, verification and production of RF and microwave devices. Manufactures of all kinds of RF and microwave transmitters such as radars, satellite up- and down-converters need to ensure that their equipment spurious emissions are within the specified limits.

Some transmitter and receiver devices, especially in aerospace & defense applications need to fulfill very stringent spurious emissions limits. This implies searching for very low level spurs within wide frequency ranges. Thus a very low resolution bandwidth (RBW) is required to make the measurements with low noise floor and high sensitivity. Moreover the location of the spurs in the spectrum is often not known beforehand, i.e. a very large frequency range has to be measured with narrow resolution bandwidths, sometimes of only a few Hz, which increases the measurement time. Even working with fast spectrum analyzers with FFT filters a spur search may take several hours or even days.

The new approach with the R&S®FSW-K50 spurious measurements application reduces the measurement time and automates the measurements when looking at low level spurs of -120 dBm or below.

2 Spurious emission measurement with spectrum analyzers — performance parameters

Spurious measurements require measuring large frequency ranges with a very high sensitivity or very low noise floor. In addition to the spectrum analyzer's thermal noise floor, the resolution bandwidth filter and measurement detector are the main factors that determine performance and speed.

2.1 Resolution bandwidth vs thermal noise floor – considerations for spurious measurements

The resolution bandwidth filter establishes the resolution bandwidth (RBW) of the spectrum analyzer. The lower this resolution bandwidth, the higher the spectral resolution. RBW influences the displayed noise floor and crucially, the sweep speed of the spectrum analyzer. In general use, the RBW is automatically set by the spectrum analyzer somewhere between 1% and 4% of the selected frequency span; this is a good value which is narrow enough to suppress spectral components outside the channel to be measured and wide enough to achieve acceptable measurement speed.

The RBW can also be adjusted by the user. If a given RBW is reduced by a factor of 10, the noise floor of the measurement will be lowered by 10 dB and vice versa. This is shown graphically in the figure below.

For spurious measurement applications the RBW usually needs to be reduced to help lower the noise floor in order to meet the test requirements: Thermal noise floor should typically be about 10 dB below the limits that are stated for a spurious emissions test to result in an acceptable signal to noise ratio (SNR) and correspondingly low uncertainty contribution of the noise.

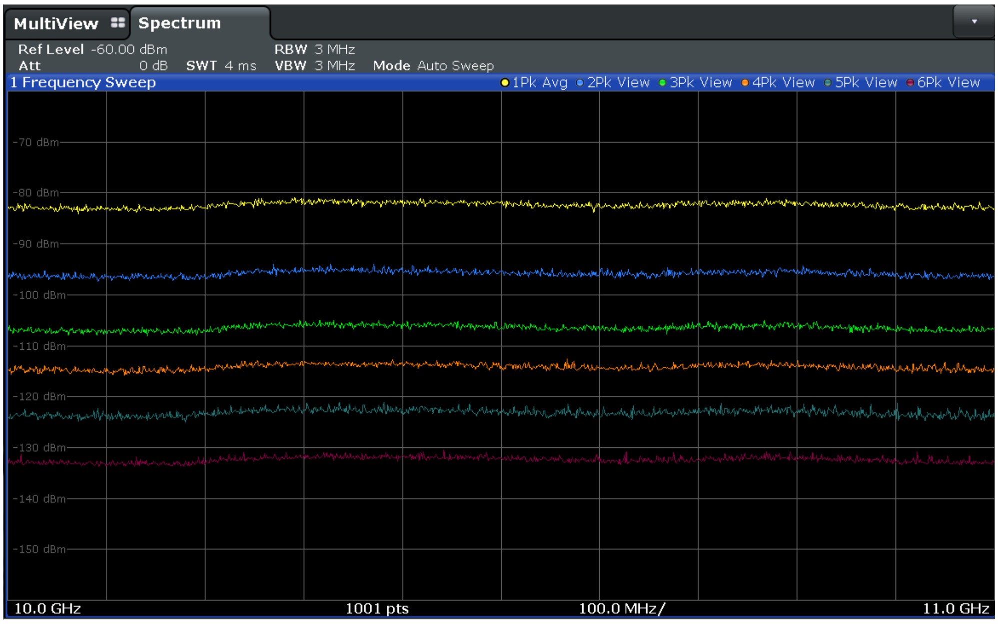

Figure 2 Changes in the displayed noise floor for RBW changing between 3 MHz (yellow trace) and 10 Hz (red trace) for 1 GHz span

When the resolution bandwidth is not defined in the test requirement, it is possible to calculate the required resolution bandwidth for a given maximum allowed noise level according to the formula below.

$$RBW\ (Hz) = 10^{\frac{Maximum\ Noise\ Level(dBm) - Noise\ Floor(\frac{dBm}{Hz})}{10}}$$

where:

- the maximum noise level corresponds to the maximum allowed spur level, with a certain margin to achieve sufficient signal to noise ratio.
- the thermal noise floor of a spectrum analyzer is determined by design and specified as the Displayed Average Noise Level (DANL) in a given resolution bandwidth (i.e. RBW 1 Hz). A typical value for a high performance spectrum analyzer is about -155 dBm in 1 Hz bandwidth.

According to the equation above, an RBW of around 3 kHz would be required for a high performance spectrum analyzer with a noise floor of -155dBm/Hz, to achieve a -120 dBm spur measurement, assuming 10 dB SNR.

The higher the spectrum analyzer's thermal noise floor, the lower the RBW needed to meet the measurement requirements and the longer the sweep time becomes. Therefore it is recommended to use a high performance spectrum analyzer with DANL as low as possible for spurious measurements, especially if the spur limit is -120 dBm or below.

The RBW selected not only defines the frequency resolution and the noise floor of the measurement, it is also the main limitation of sweep speed, i.e. the lower the RBW the longer the measurement time required to measure a given frequency range. The required sweep time increases inversely with the square of the resolution bandwidth according to the below formula.

$$SWT(s) = k * \frac{Span\ (Hz)}{RBW(Hz)^2}$$

Where:

SWT is the sweep time, Span is the frequency range, and k is the correction factor for the settling time of the resolution filter (k=1 for FFT RBW filter and between 2 and 3 for older, analog spectrum analyzers)

It is therefore important to choose a bandwidth that just fits to the spurious level requirement in order to keep the total measurement time acceptable.

The instruments noise floor varies along the frequency range; this means that different RBWs will need to be used at different frequencies. In traditional spurious search applications the RBW which is used at each frequency needs to be calculated and entered manually in the analyzer.

2.2 Measurement detector choice for spurious measurements

In modern spectrum analyzers the resolution of both the level and the frequency display is limited to the display resolution (number of pixels). Therefore, especially when large spans are displayed, there are many more measurement samples than display pixels in the frequency axis. This means a certain amount of measurement samples have to be combined into one single pixel (point displayed on the screen).

The measurement detector choice determines how the measurement samples are weighted to get a single measurement value per display pixel. Spectrum analyzers offer different measurement detectors. The principles of the detectors are shown in Figure below.

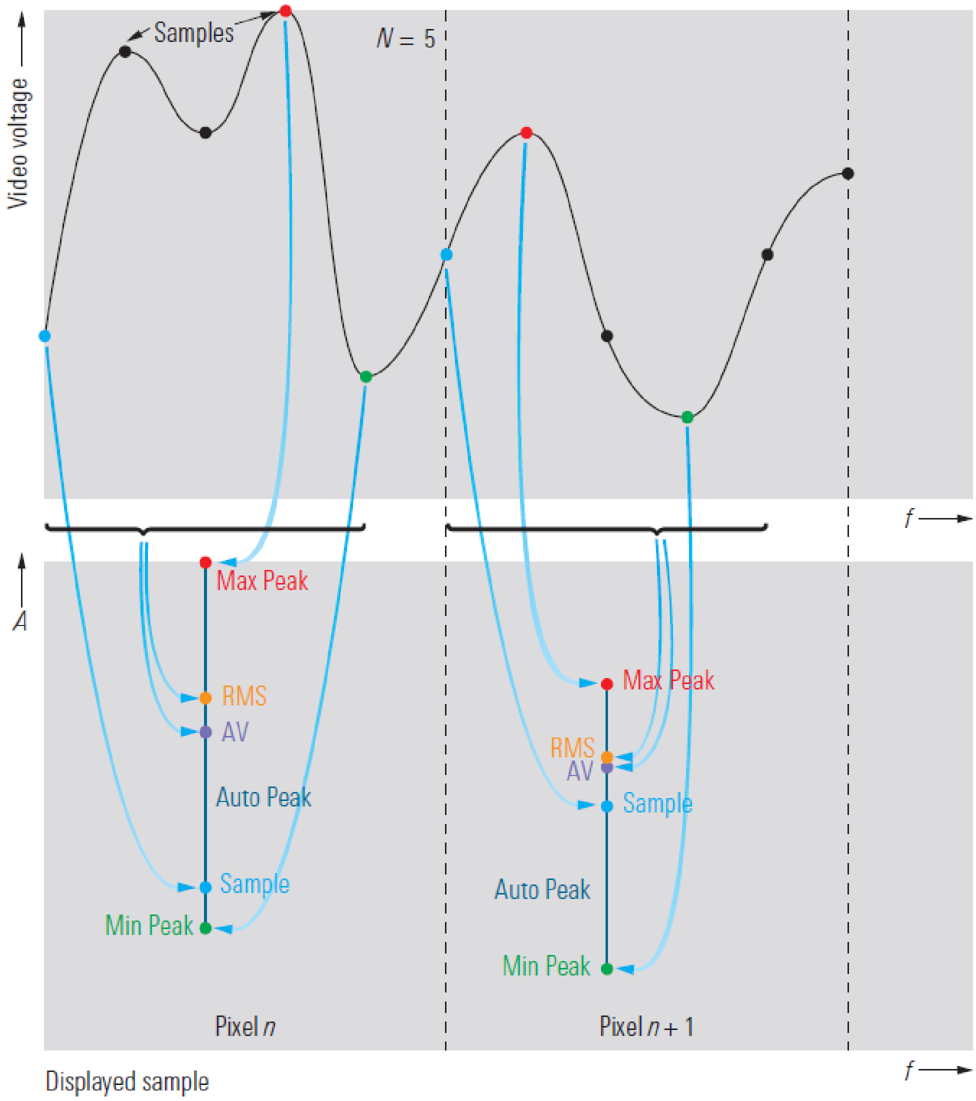

Figure 3 Selection of sample to be displayed as a function of detector used [1]

Spurious emissions measurements for very low level signals are typically performed with a peak detector. The max peak detector displays the maximum value. From the samples allocated to a pixel the one with the highest level is selected and displayed. The advantage of the peak detector compared to other detector types is that even if wide spans are displayed with very narrow resolution bandwidth (span/RBW >> number of pixels on frequency axis), no input signals are lost and the result of the measurement is a worst-case scenario.

3 Speed up spurious measurement using the optimum RBW

The spurious search algorithm within FSW-K50 automates and speeds up spurious measurements when looking at very low level spurs. This new technique requires the user to set only the frequency ranges to be investigated and the maximum allowed spurious level. A 10 dB SNR margin between the instrument noise floor and the specified spurious detection threshold is used per default. However, the SNR margin can be also changed by the user along with the other relevant parameters shown in Figure 4. Users don't need to set the RBW for each frequency range like in traditional applications because the algorithm calculates it automatically.

	Range 1	Range 2	Range 3	Range 4
Range Start	30 MHz	300 MHz	500 MHz	1 GHz
Range Stop	300 MHz	500 MHz	1 GHz	2 GHz
Spur Detection Threshold Start	-132 dBm	-130 dBm	-125 dBm	-120 dBm
Spur Detection Threshold Stop	-132 dBm	-130 dBm	-125 dBm	-120 dBm
Limit Offset to Detection Threshold	0 dB	0 dB	0 dB	0 dB
Peak Excursion	3 dB	3 dB	3 dB	3 dB
Minimum Spur SNR	10 dB	10 dB	10 dB	10 dB
Maximum Final RBW	100 kHz	100 kHz	100 kHz	100 kHz
Auto RBW	On	On	On	On
RBW	Auto	Auto	Auto	Auto
Number of FFT Averages	2	2	2	2
Ref Level	0 dBm	0 dBm	0 dBm	0 dBm
RF Attenuation	10 dB	10 dB	10 dB	10 dB
Preamp	Off	Off	Off	Off

Figure 4 Exemplary measurements settings for a wide spurious search

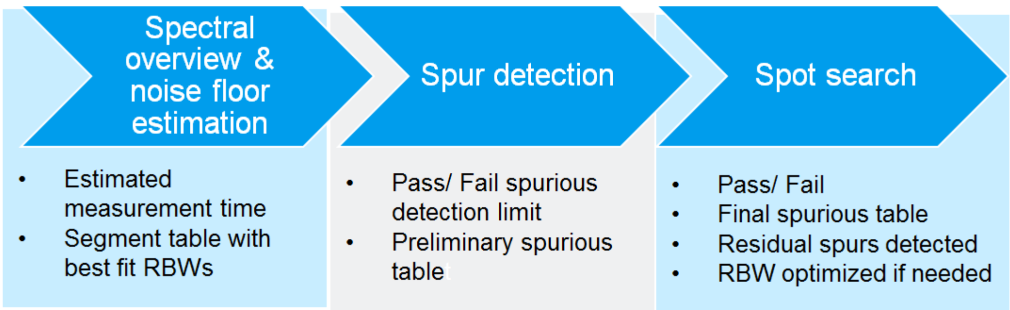

Figure 5 Measurement process in the FSW-K50 spurious search algorithm: 3 sweeps /measurement steps.

The FSW-K50 application first performs a fast reference sweep in the defined frequency ranges to obtain an overview of the input signal, the so called “spectral overview”. The spectral overview allows the application to gather the necessary information about the signal to estimate the noise floor for the user defined frequency span and other settings.

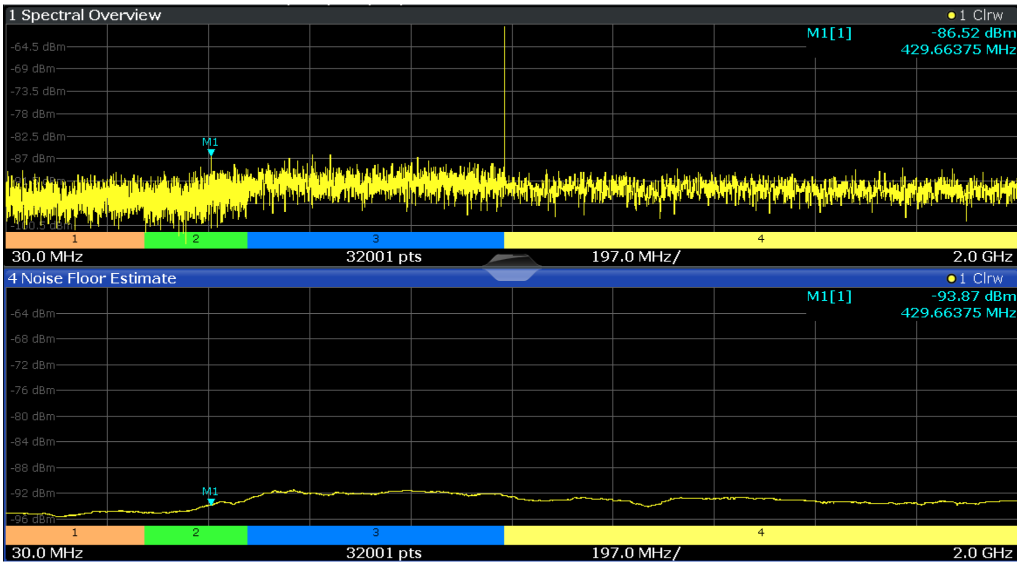

Figure 6 Measurement screen of spectral overview and noise floor estimate for a 2 GHz span measurement.

The noise floor estimation is required to set the RBW optimally for subsequent measurement steps: due to noise variations across the frequencies, the RBW required to achieve the user-defined spur detection threshold varies. Each frequency range is thus split into smaller segments that use a constant RBW setting for the complete segment span. The frequency span of the segments depends on the signal and noise conditions and on the settings. As a result, a segment table is created.

Segment Table | Spur Table

Range	(1) 30 MHz ... 300 MHz	(2) 300 MHz ... 500 MHz		(3) 500 MHz ... 1 GHz	(4) 1 GHz ... 2 GHz	
Segment Start	30 MHz	300 MHz	437.740385 MHz	500 MHz	1 GHz	1.271820149 GH
Segment Stop	300 MHz	437.740385 MHz	500 MHz	1 GHz	1.271820149 GHz	1.343231546 GH
RBW	1 Hz	1.1 Hz	1 Hz	2.3 Hz	10.6 Hz	11.6 Hz
Ref Level	0 dBm	0 dBm	0 dBm	0 dBm	0 dBm	0 dBm
RF Attenuation	10 dB	10 dB	10 dB	10 dB	10 dB	10 dB
Preamp	Off	Off	Off	Off	Off	Off

Figure 7 Segment table calculated after the reference sweep and noise floor estimation. Shows the RBW required to measure at each frequency for the spurious limits set by the user.

After the reference sweep the FSW-K50 application performs a second sweep, a so called spur search using the RBW settings calculated in the previous step. The results of this sweep produce a preliminary table containing each detected spur.

A third and final sweep, the spot search, is performed over very narrow spans around each spur detected in the previous step. The spot search is required to eliminate noise, refine the spur levels and frequencies, as necessary to meet the user SNR requirements. Thus it determines whether the peak is a real spur, an artifact of noise, or generated internally by the analyzer (residual spurs). The RBW for these spot searches may be reduced further compared to the spurious detection sweep. The resulting "Spurious Detection Table" contains all peaks that still exceed the detection threshold, and are really a spur.

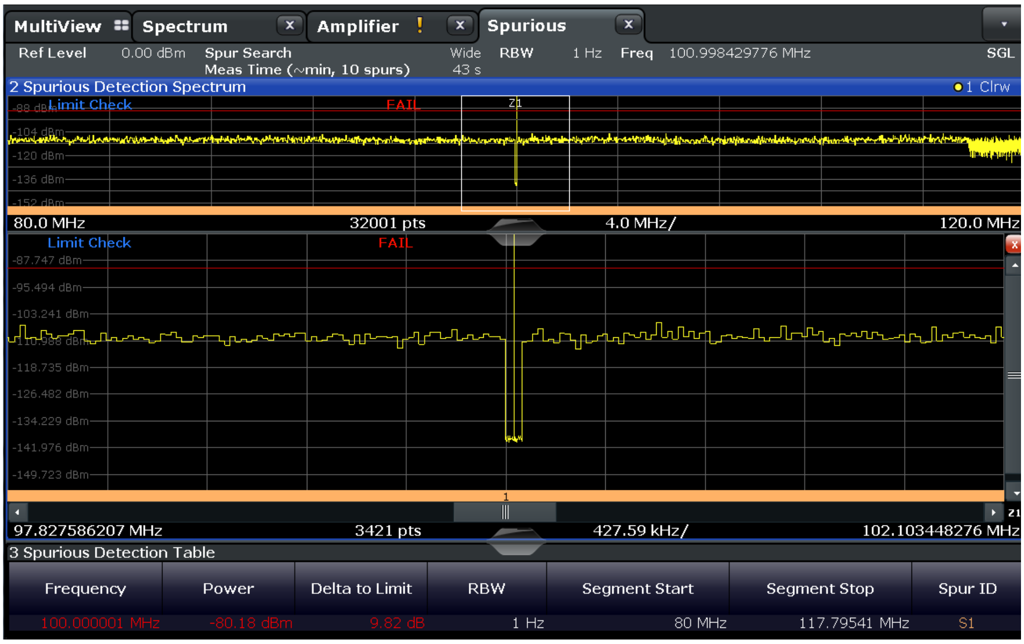

Figure 8 Zoom into a spot search: the RBW around the spur is reduced to lower the noise floor and fulfill the SNR requirement set by the user and determine whether the peak is a real spur.

The algorithm within the FSW-K50 application automatically sets the optimum RBW: The RBW is as low as necessary to recognize the real spurs at the required frequencies but not unnecessarily low in those frequency ranges where no potential spurs have been found. This technique speeds up spur searches up to 50 times in comparison with traditional spur search methods, when wide frequency ranges and very stringent spur detection limits are applied. The table below a shows comparison of the required measurement time with traditional spurious search applications and the FSW-K50 spurious measurement application.

RBW / Noise (dBm) 1 GHz span	R&S FSW spectrum analyzer, FFT Sweep Measurement speed (s)	R&S FSW spectrum analyzer, FSW-K50 measurement application Measurement speed (s)
1 Hz / -140	12246	200
2 Hz / -138	3088	84
3 Hz / -135	1384	35
5 Hz / -132	507	12
10 Hz / -130	132	7
20 Hz / -128	36	6
30 Hz / -125	17	5
50 Hz / -122	7.1	4
100 Hz/-120	4.1	3

Table 1 Measurement times comparison with traditional and new spurious search applications

3.1 Residual spurs identification

Residuals are spurs that are created by the analyzer itself. These spurs are identified by the FSW-K50 spurious measurements application automatically; they can be displayed or removed from the measured results.

3.2 Directed search at predefined frequencies

In some cases potential spur frequencies are known beforehand, like harmonic frequencies for example. For these cases the FSW-K50 application also provides directed search measurements at predefined discrete frequencies with a small span around each frequency.

The measurement steps for both wide and directed search measurements are the same; however, because the span is smaller, the directed search saves measurement time and can provide more precise results, using a larger SNR.

It’s possible to combine a wide search measurement and directed search measurement. A function allows transferring the frequencies of interest of a previous wide search into a directed search, simplifying the setup for a directed spur search.

4 Summary

The R&S®FSW-K50 spurious measurements application automates and speeds up the spurious search, especially when looking at very low level spurs over a broad frequency range. The user only needs to enter the frequency range and the desired spur detection level. The application calculates and applies the optimum RBW to measure at each frequency. Very narrow RBWs will be used only in those frequencies where potential spurs have been found. Spurious search becomes up to 50 times faster than traditional spurious search measurements with high performance spectrum analyzers.

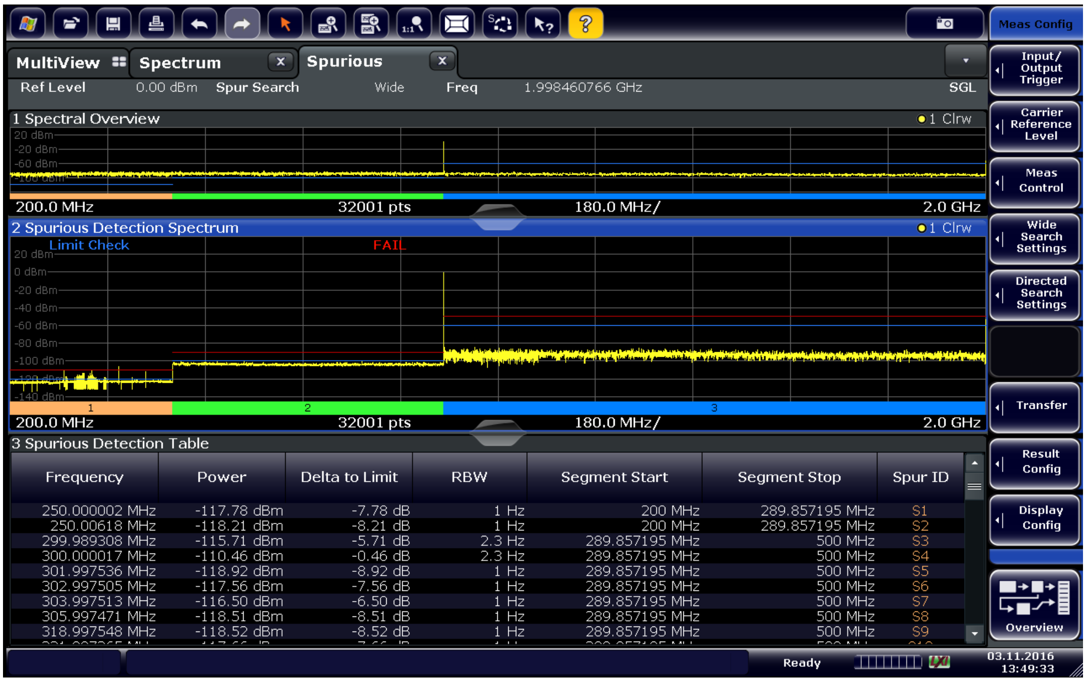

Figure 9 FSW-K50 Spurious measurement application screen: the spectral overview shows the reference sweep to calculate the necessary RBW. The spurious detection spectrum shows the pass /fail indication according to the spur detection limits. The spurs detection table shows the detected spurs: frequency, power level, RBW used for the measurement, etc.

5 References

[1] C. Rauscher, Fundamentals of Spectrum Analysis, Rohde & Schwarz, Munich, ISBN 978-3-939837-01-5

[2] K-U. Sander, "Speed considerations for Spurious Measurements with Spectrum Analyzers", retrieved June 2017 at www.rohde-schwarz.com/appnote/1EF80

[3] R&S®FSW-K50 Spurious Measurements User Manual, Rohde & Schwarz, Munich

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