# Speed considerations for Spurious Level Measurements with Spectrum Analyzers
# Application Note

**Products:**

|   R&S®FSU

|   R&S®FSV

|   R&S®FSW

The measurement speed for spurious signal measurements is mainly defined by the spectrum analyzer sweep speed. With traditional swept spectrum analyzers and tight spurious limits the measurement can easily take hours or even a full day. This application note describes the differences in sweep speed between classical swept spectrum analyzers and modern spectrum analyzers with a wide-band FFT process, and how this improves the measurement speed for general spurious measurement.

ROHDE&SCHWARZ

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# 1 Introduction

Spurious emissions of a device under test are caused by unwanted effects such as harmonic emissions, parasitic emissions, intermodulation products and frequency conversion products. Low level spurious emission measurements are one of the most time-consuming measurements on transmitters, as it requires a very low noise floor. A small resolution bandwidth is necessary to reduce the noise floor of the spectrum analyzer. The narrow bandwidth leads to long measurement time and low sweep rates. The spectrum analyzer architecture has a great influence on the speed of the spurious emission measurement.

This application note compares the differences in architecture between the swept spectrum analyzer approach and a modern broadband FFT-based signal- and spectrum-analyzer and how it affects the sweep speed. The theoretical background for the sweep speed is explained, and practical results for spurious measurements are derived.

# 2 Overview

The general spurious emission measurement requires a low noise floor over a wide frequency range. At the lower end of the dynamic range the thermal noise floor of the spectrum analyzer is the most important limiting factor. It typically should be 10 dB below the limits for spurious emissions for an acceptable signal to noise ratio. While the inherent noise floor is defined by the design of the spectrum analyzer, the available measurement range is also limited by the selected resolution bandwidth and the used detector. If the bandwidth is reduced by a factor of 10, the noise floor of the measurement will be lowered by 10 dB. The price for the lower noise floor is a dramatically increased measurement time. It is therefore important to choose a bandwidth that just fits to the spurious level requirement in order to keep total measurement time acceptable.

## 2.1 Thermal Noise Floor

For general spurious measurements the setting of the resolution bandwidth filter can be adjusted to reduce the noise floor of the spectrum analyzer below the test requirement. The thermal noise floor of a spectrum analyzer is 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. The noise floor within the spurious measurements depends on the required bandwidth and can be determined from the DANL. When the resolution bandwidth is not defined in the test requirement, it is possible to calculate the required resolution bandwidth for a given maximum noise level.

For correction of the noise floor due to resolution bandwidth the following formula applies:

$$DANL\,(RBW) = DANL\,(1\,Hz) + 10 \cdot \log\left[\frac{RBW\,/\,Hz}{1\,Hz}\right] \qquad (1)$$

Where:
DANL (RBW)     = Displayed average noise level in the selected RBW
DANL (1 Hz)     = Displayed average noise level in 1 Hz bandwidth
RBW / Hz          = Selected Resolution bandwidth

For example, with 1 kHz resolution bandwidth the displayed average noise floor has to be corrected by 30 dB.

## 2.2  Detector Influence

Modern spectrum analyzers display the spectrum using a raster scan on a LC display. Characteristic for these displays is that the number of pixels in the frequency axis is limited.  When measuring wide frequency ranges with narrow resolution bandwidth (pixel width wider than the RBW) like in the spurious signal measurement, the level information of each frequency point has to be compressed into the available amount of display pixels.  Spectrum analyzers use a set of detector functions to perform this task, with peak, sample and RMS being the most frequently used types of detector functions.
The sample detector generates one level measurement value per pixel on the x-axis. This of course can cause a total loss of signal information, especially if the RBW is small compared to the frequency range covered by one pixel.  However, the sample detector is typically used to describe the noise floor of a spectrum analyzer.
For mean power measurements most analyzers provide an RMS detector.  With the RMS detector the level envelope is sampled at a high sampling rate and all samples are used for the mean power calculation.  The spurious emission measurement often requires the measurement of mean power, especially when noise-like or wideband modulated signals shall be measured.  The displayed average noise floor stated in the data sheet is measured with the sample detector using video or trace averaging. Due to the logarithmic scaling of the trace and the averaging process the DANL is 2.51 dB lower than the noise power.  Therefore the specified DANL has to be corrected by 2.51 dB to get the noise power.
In case of pulsed systems like radar transmitters, the spurious emission measurement is typically performed with a peak detector.  The advantage of the peak detector is that no signals will be lost and the result of the measurement is a worst-case scenario.  The peak detector captures all level results while the spectrum analyzer sweeps across the frequency range of a pixel, and each pixel shows the peak result of the frequency range that is covered by this pixel.  The frequency resolution of the trace is limited to the span divided by the sweep points.  For improved frequency resolution of the spurious measurement result trace, the sweep points can be adjusted to a higher number.

The noise floor for measurements with the peak detector is much higher than the sample or RMS detector, as the detector will allways capture the highest peak reading. The peak value of the noise floor depends on the observation time for each pixel. As the noise floor of the spectrum analyzer can be assumed to be white Gaussian noise, the worst case for the difference between peak and mean power is the crest factor, which is about 12 dB. This value has to taken into account in the setting of the RBW to obtain a noise floor below the test limit.

For the comparison of spectrum analyzer architectures and their speed performance it is important to use comparable conditions. The rules for the dependencies of the noise level on the RBW value as well as on the detector are similar for all types of spectrum analyzers and can be neglected for the comparison. The DANL (averaged noise level) of the spectrum analyzer is one of the critical values to investigate. It is important to verify that all values are specified under similar conditions, most important is the value of the bandwidth as this varies between vendors. In the following sections high performance spectrum analyzers are compared. With respect to noise floor they use very similar RF frontend architectures, and thus have a very similar noise floor over wide frequency ranges. For the purpose of the comparison, a low level test limit is assumed. This test limit can be reached in both cases with sufficient margin by selecting a similar resolution bandwidth.

# 3   Comparison of Architectures

The previous chapter introduced the dependancy of the noise floor on the resolution bandwidth and the used detector. In the following chapter the practical implementation of the resolution bandwidth filter in the traditional spectrum analyzer and modern FFT-based signal analyzers will be compared.

The sweep speed of a spectrum analyzer not only depends on the selected resolution bandwidth, but also on the implementation of this filter, the selected frequency span and the overhead for processing the data and performing the frequency sweep. This implementation will turn out to be the main difference for the achievable sweep rates between swept spectrum analyzers an modern wide-band signal and spectrum analyzers.

## 3.1   Swept Spectrum Analyzer architecture

The block diagram below shows the basic concept of a traditional analog spectrum analyzer. It only includes the important components to explain the operation of the sweep, but does not show the full diagram of the RF conversion stages.
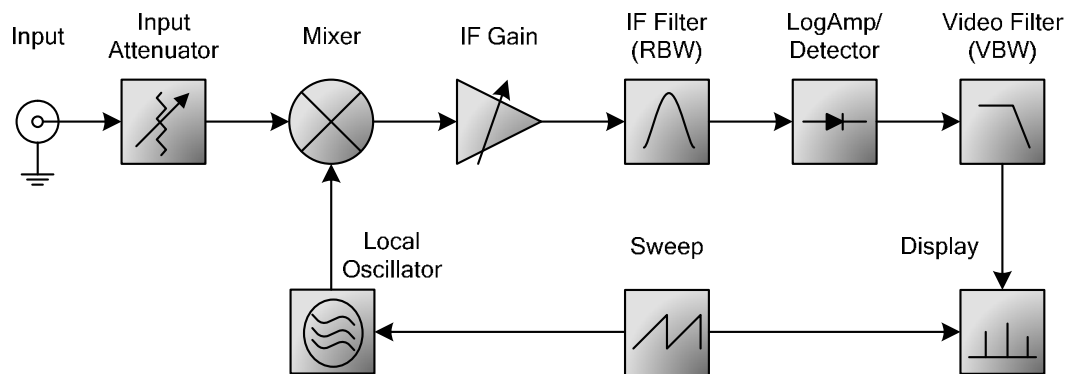
*Figure 1: Simplified block diagram of an analog swept spectrum analyzer. Diagram applies in principle also for spectrum analyzers with narrow-band digital back ends like the R&S FSU.*

In the swept spectrum analyzer a broadband input frequency range is converted through mixer stages to a final IF frequency. The local oscillator sweeps over a defined frequency range (=span), while the level measurement result is plotted on the display. The time for the sweep over the entire frequency span is the sweep time. The IF signal processing uses near Gaussian shaped analog filters to form the resolution bandwidth, which defines the ability to resolve closely spaced signals in the frequency axis. The resolution bandwidth not only defines the frequency resolution and the noise floor, it also is the main limitation of the sweep speed. The output signal of the RBW filter is processed through the detector to the video bandwidth. The purpose of the video filter is to reduce the noise on the trace. In spurious emission measurements the goal is to measure the highest peak level that exists. In this case, the video filter is normally coupled to the resolution bandwidth filter and as such has no impact on the settling time and the sweep time. For a correct level measurement on every frequency, the analog filter needs sufficient time to follow the input signal level change. For a traditional analog swept spectrum analyzer, the sweep time is therefore calculated as:

$$SWT = k * \left[ \frac{Span / Hz}{(RBW / Hz)^2} \right] \qquad (2)$$

Where:
SWT = Sweep Time in seconds
Span / Hz = Frequency Span in Hz
RBW / Hz = Resolution bandwidth in Hz
k = correction factor for the settling of the resolution filter, typ. 1 to 3

The correction factor in the above formula has an impact on the level accuracy of the measurement as it impacts the time for the resolution bandwidth filter to reach the input signal level. In most analog spectrum analyzers a remaining level error of 1% was accepted, which leads to a k-factor of 2.5.

An all-digital IF section in a modern spectrum analyzer like the R&S FSV or the R&S FSW uses a digital implementation of a swept resolution bandwidth filter. In these analyzers, the settling of the IF filter is predicted mathematically and the sweep time is decreased, accepting a limited amount of level error for the settling process of the filter. This error is compensated in the software as the behaviour of the filter is predictable. This improvement allows to reduce the k-factor to values of about 1 and still perform accurate measurements.

Example: 1 GHz Span, 1 kHz RBW:

$$SWT\,(s) = 1 \cdot \left[ \frac{10^9 \; Hz}{1 \, kHz^2} \right] \qquad\qquad (2a)$$

For the given span and bandwidth values the sweep time is 1000 s in this case. The sweep time for other ranges can be calculated accordingly.

The total measurement time for a swept measurement does not only include the sweep time. The spectrum analyzer will process all sweep results, draw a trace or might have to report data to a remote controller. In case of narrowband swept measurements the additional processing time will not add a lot of time and is neglectable for the total measurement time. The overall time consumption for narrowband resolution filters in a swept spectrum analyzer makes this concept unattractive. Therefore in spectrum analyzers the swept measurement is replaced by a digital FFT based solution to increase sweep speed.

## 3.2 Wideband Signal- and Spectrum Analyzer

The block diagram below shows the basic concept of a FFT based signal- and spectrum analyzer. Only the main components that are important to understand the difference to the swept spectrum analyzers are shown.
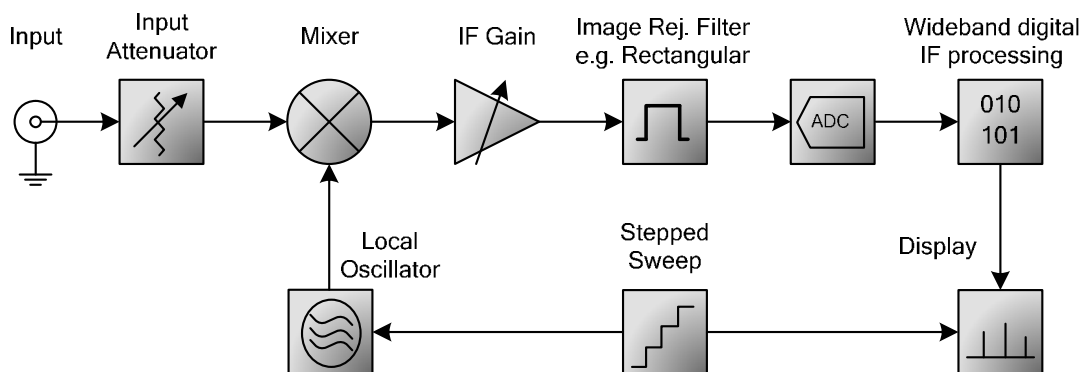


*Figure 2: Simplified block diagram of a digital back end spectrum analyzer like the R&S FSW.*

The important difference is the IF filter and the subsequent signal processing. While the analog and narrow-band digital RBW filters are swept across the frequency range for analog spectrum analyzers, modern signal- and spectrum analyzers perform an FFT to implement the resolution bandwidth filter. Therefore, the remaining filters in the IF section of these analyzers are mainly designed for image rejection or for limiting out of band signals in front of the A/D converter. Typically, wide-band signal- and spectrum analyzers have two to three analog filters implemented with different bandwidths in front of the A/D converter. The digitized IF signal is then processed by an FFT and subsequent detectors and video filters. The sweep across the frequency span is not performed as a linear sweep, but instead is replaced by a set of FFTs at discrete frequency settings of the oscillators in the down-converter section.

**Note:** The block diagrams in this application note show the wide-band digital spectrum analyzer with an analog IF filter that is rectangular shaped. This is of course not exactly correct, but was chosen to visualize the difference to the Gaussian shaped RBW filter. The key figure in terms of influence on the sweep rate is not the filter shape, but the filter bandwidth and thus the available coverage. FFT processing has been used for many years for very small RBW filters and spans. With modern spectrum analyzers and their wide bandwidth A/D converter architecture, the frequency coverage of each FFT may cover 100 MHz or more.

The sweep time of such an FFT based spectrum analyzer consists of three main parts:
- aquisition time of the samples used for the FFT
- processing time of the FFT
- frequency steps of the down-converter

The acquisition time for the FFT is inverse proportional to the selected resolution bandwidth.

$$AQT\,(s) = \left\lceil \frac{k}{RBW\,/\,Hz} \right\rceil \tag{3}$$

Where:
AQT (s) = Aquisition Time of the FFT in seconds
RBW / Hz = Resolution Bandwidth in Hz
k = correction factor for the FFT weighting filter, typ. 2 to 4

The correction factor k in the above formula is dependent on the weighting filter used for the FFT and thus depending on the filter design. Many spectrum analyzers use flattop filters for best level accuracy and thus use a factor of 2 to 4. For 1 kHz RBW the aquisition time is < 4 ms per FFT. The acquisition time is inverse proportional to the RBW. This is one of the main differences to the swept analyzer, where it is inverse proportional to the squared RBW and thus has a bigger impact with small bandwidth values. After the signal has been acquired, the FFT is calculated. The data processing time of the FFT is depending on the architecture and has a large impact on the overall measurement speed. Another important factor for the total measurement time is the available capture bandwidth. This bandwidth is defined by analyzer design and impacts the number of frequency steps to cover the frequency range of interest. For wide frequency ranges this is important: the wider the capture bandwidth, the lower the number of required frequency steps.

The total sweep speed for the FFT based spectrum analyzer is difficult to predict as only one of at least three contributing values is exactly known. The two other parameters of the three important numbers that impact the speed are depending on the architecture and are not specified in most cases. The next chapter compares the total speed for some typical measurements to give a better inside view.

# 4 Spurious Measurements: Speed results

The previous chapters introduced the difference between typical spectrum analyzer architectures and how the sweep time is affected by the RBW filter. In this chapter measurement results for spurious emission measurements on different architectures and instrument types will be compared. For the comparison of spectrum analyzer architectures similar conditions especially for the averaged noise level are important. This allows the use of the same bandwidth and thus a direct comparison of the sweep speed results between the architectures. The high performance spectrum analyzers used for this comparison have very similar RF frontend architectures and thus have a very similar noise floor.
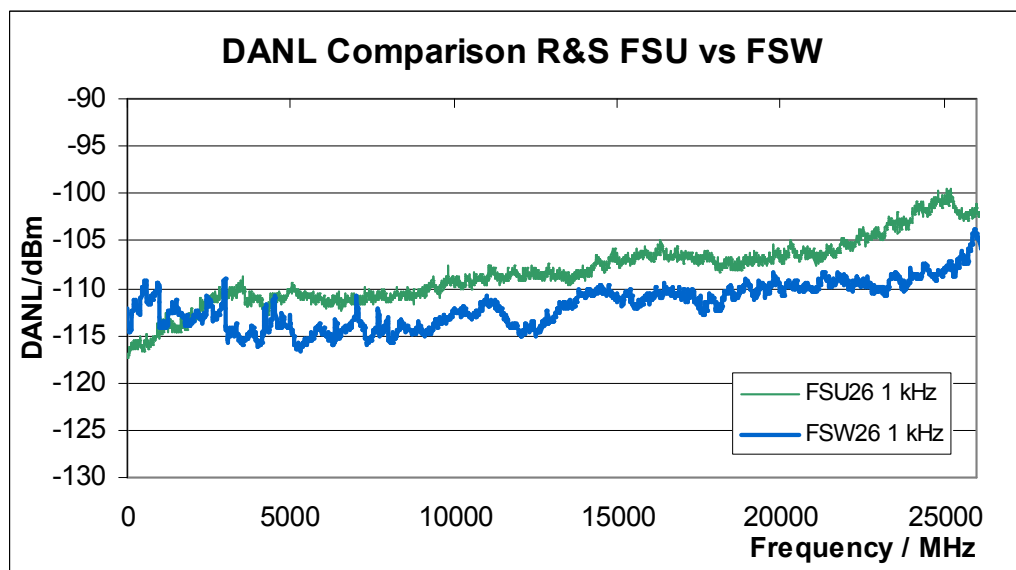


*Figure 3: Peak Noise level comparison between R&S FSU ( swept spectrum analyzer) and R&S FSW (wide-band digital back end with FFT) for the same RBW setting (1 kHz).*

Figure 3 shows the comparison of the noise floor of the R&S FSU and the R&S FSW. Both instrument models are high performance spectrum analyzers of different generations. The R&S FSU is mainly designed as a swept spectrum analyzer and uses digital resolution bandwidth filters (k=1). In addition, the FSU can perform FFT analysis for a limited resolution bandwidth range up to 30 kHz. The R&S FSW is designed as a wideband signal analyzer and automatically selects FFT filtering whenever this will result in a shorter sweep time. Both instrument types reach a similar noise floor for the frequency range up to 26.5 GHz. For the speed comparison a similar resolution bandwidth of 1 kHz is therefore selected to allow direct comparison.

For the traditional spectrum analyzer with swept resolution bandwidth filters, the sweep time can easily be calculated. The result of this calculation is a sweep time of 26500 s. This is number that is outside of the capabilities of most spectrum analyzers, as the maximum sweep time is typically limited arround 10,000 s. As the sweep time is proportional to the span, the subsequent measurements in this comparison are performed in 1 GHz span segments and the sweep time result is shown per GHz.

## 4.1  Speed result for the swept Spectrum Analyzer

The speed performance of the swept spectrum analyzer is measured with an R&S FSU.  The resolution bandwidth is set to 1 kHz to reduce the peak level noise floor to about -110 dBm.  The video bandwidth is coupled to the resolution bandwidth and has therefore no effect on the sweep speed.  The measurement is performed from 10 MHz to 26 GHz with 1 GHz span for each segment to keep the auto coupled sweep time within the allowed range.  The measurement is controlled from a remote controller to track the real total measurement time including processing overhead, data transfer etc.
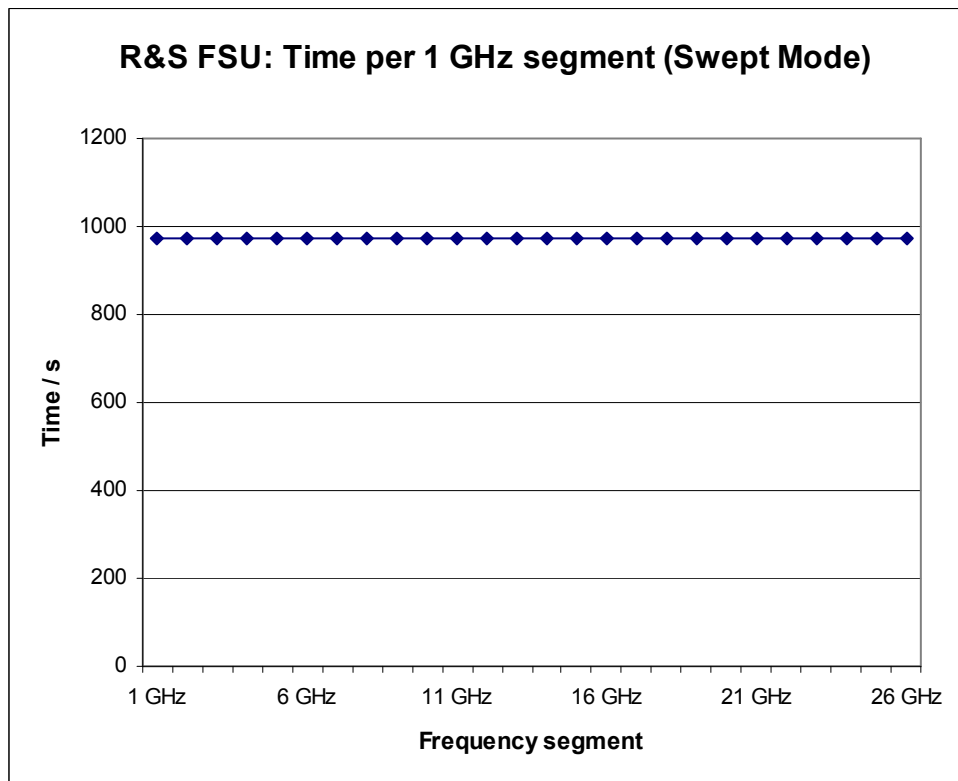


*Figure 4: Total measurement time per 1 GHz span for the R&S FSU spectrum analyzer (RBW = 1 kHz)*

As explained earlier, the total measurement time is about 1000 seconds per 1 GHz segment of frequency sweep range.  A practical spurious measurement will take very long time especially when low level limits must be reached.  The average sweep time is:

- RBW 1 kHz:        1000 s / GHz    Peak Noise level @ 10 GHz: - 100 dBm
- RBW 10 kHz:      10 s / GHz        Peak Noise level @ 10 GHz:  - 90 dBm

As the noise level and the sweep time follow the calculation rules given earlier in this application note, the expected noise level and sweep time can be calculated for other settings of interest.  It is very clear that spurious emission measurements with tight limits are very time consuming on the traditional swept spectrum analyzer.

The next chapter will give some information about possible improvements to obtain results faster. The R&S FSU spectrum analyzer is able to perform the same measurement using FFT based resolution bandwidth filters. This will speed up the measurement for bandwidths < 10 kHz as the signal acquisition process and the FFT filter processing is much faster than a traditional sweep.

## 4.2  Speed results for FFT based Spectrum Analyzers

The speed performance of the FFT based spectrum analyzer is compared between the R&S FSU and the R&S FSW. The resolution bandwidth is set to 1 kHz for a direct comparison to the measurements on the swept analyzer. The video bandwidth is coupled to the resolution bandwidth and has therefore no effect on the sweep speed. The measurement is performed from 10 MHz to 26 GHz with 1 GHz span for each segment. The measurement is controlled from a remote controller to track the real total measurement time. In case of an FFT based measurement this is important as the processing overhead is a main part of the total time. Many spectrum analyzers perform estimations of this processing time but do not give accurate information for a comparison.
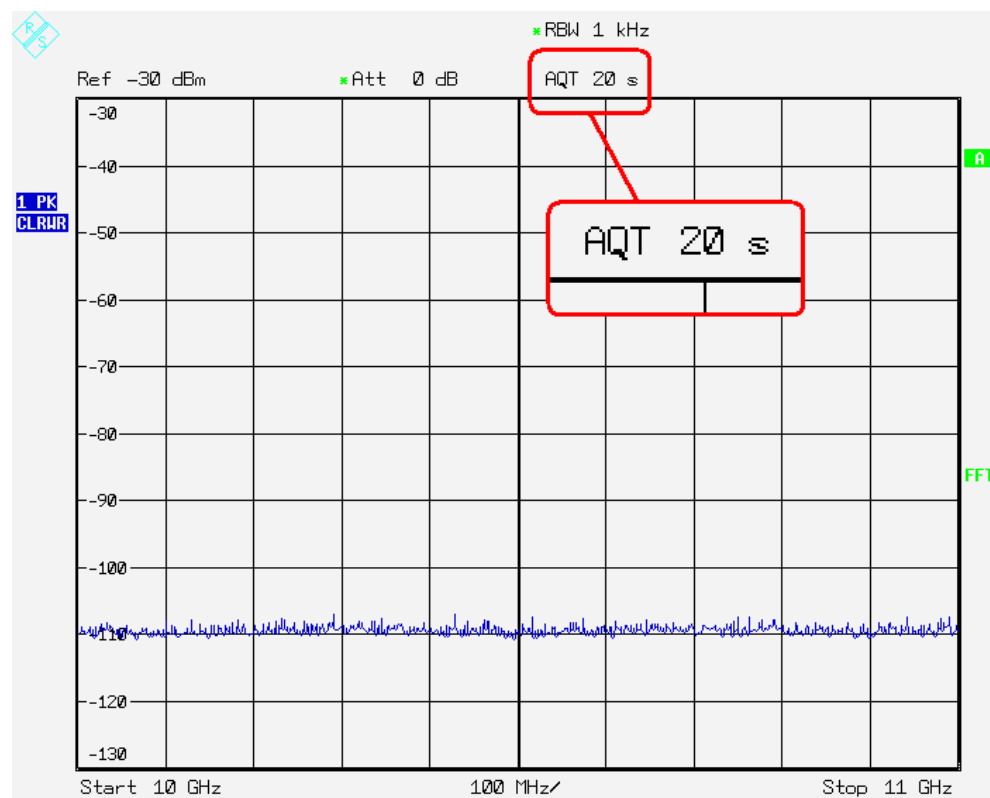


*Figure 5: Sweep time display on the R&S FSU in FFT mode (Span 1 GHz, RBW 1 kHz)*

The screen copy in figure 5 shows the measurement result on the R&S FSU for one of the segments. Note the AQT (=aquisition time) information in the header above the spectrum result. The AQT of 20 s refers to the total time while the input signal was captured.

This is an important information since it directly relates to the raw measurement time. This time is very important in cases where the test signal may be modulated or even pulsed. In these cases it is important that the spectrum analyzer spends a sufficient amount of time on every frequency point to capture the signal. The AQT does not allow a direct calculation of the total sweep time which includes all processing time as well. The processing time of the FFT will contribute to a large fraction to the total measurement time.
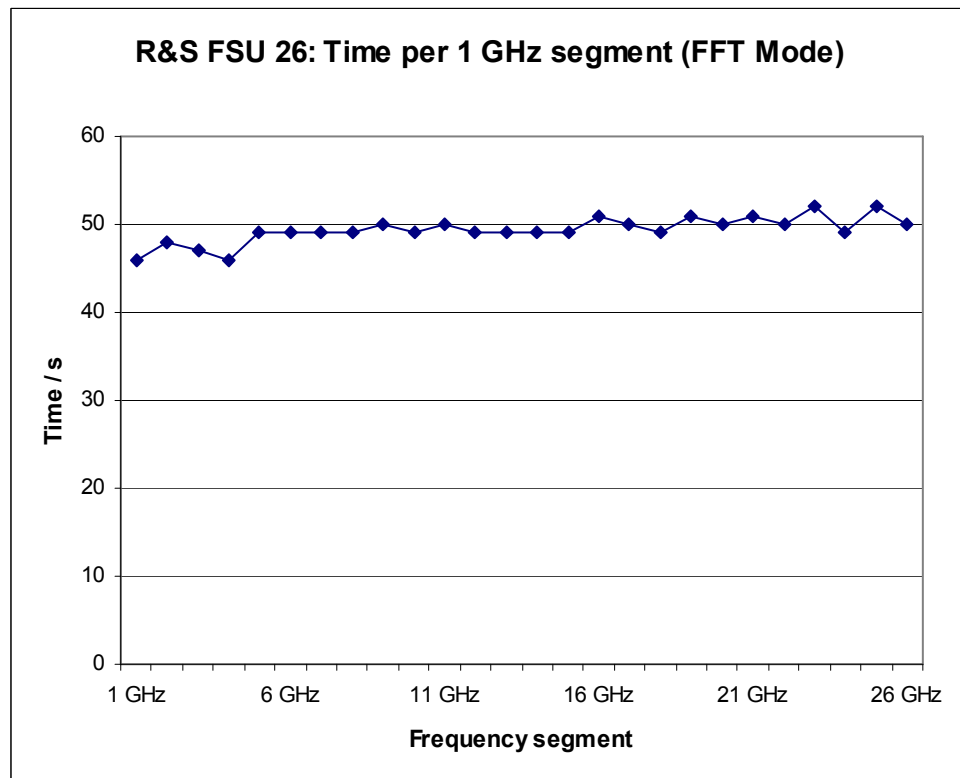


**Figure 6: Measurement time per 1 GHz span for the R&S FSU spectrum analyzer (RBW = 1 kHz)**

Figure 6 shows the result of a spurious emission measurement performed on the R&S FSU in FFT mode. All other settings are equal to the measurement in swept mode. The R&S FSU performs FFT processing within a limited capture bandwidth using an analog resolution bandwidth filter in front of the A/D converter. Due to the limited bandwidth capabilities many FFTs must be performed, which has a large impact on the total processing time. The data aquisition time for this measurement was 20 seconds as shown in the screen copy, the total measurement time for a FFT sweep from 10 MHz to 26 GHz is about 27 minutes. This is a huge improvement compared to the measurement with a swept resolution bandwidth filter that would take over 7 hours for the same settings.

- Span 26 GHz, RBW 1 kHz, Swept Filter:    433 min (~ 17 min / GHz)
- Span 26 GHz, RBW 1 kHz, FFT Filter      23 min (~ 1 min / GHz)

Improvement: > 15 times faster within the same instrument

Further improvements for this measurement are possible with modern wideband signal- and spectrum analyzers.

The R&S FSW performs FFTs using wide capture bandwidths and thus limiting the number of FFTs required to cover the same span as before. While the widest capture bandwidth for the R&S FSU is about 2 MHz, the R&S FSW will capture up to 80 MHz bandwidth in a single FFT acquisition. The benefit of the wider capture range is a lower amount of FFTs to process and less frequency steps to perform.

As a consequence of the wider FFT capture range, each single FFT will include much more samples to process. The R&S FSW is equipped with a high speed controller to reduce the processing time of the resolution filter signal processing by factors compared to the R&S FSU.
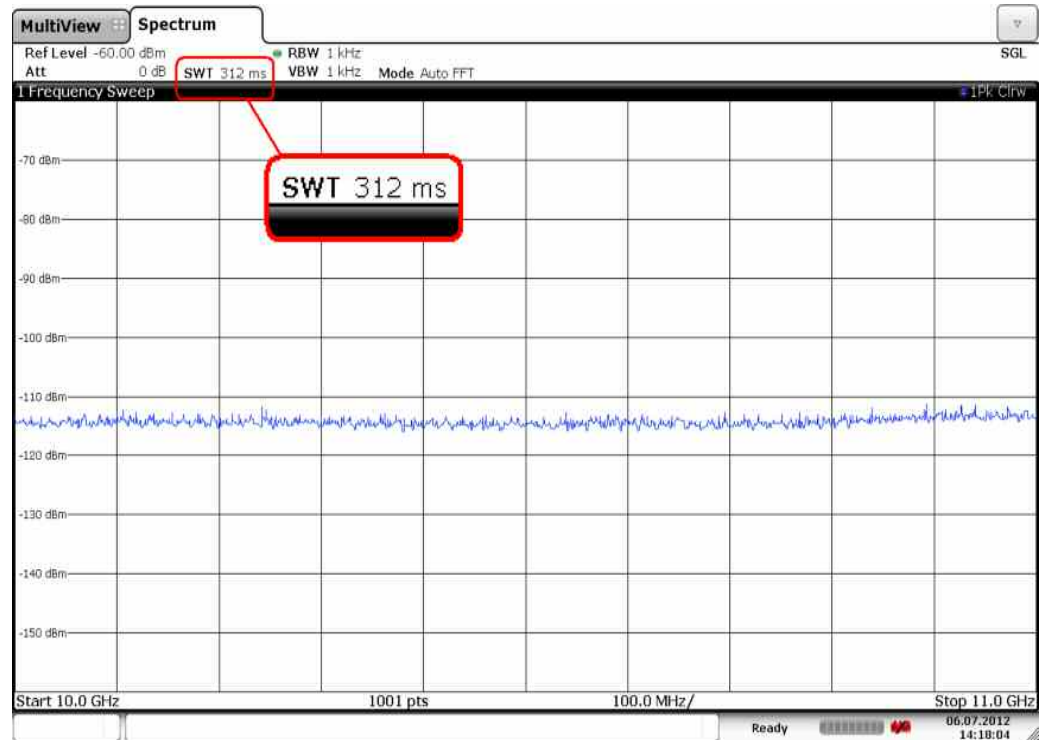


*Figure 7: Sweep time display on the R&S in FFT mode (Span 1 GHz, RBW 1 kHz)*

The screen copy in figure 7 shows the measurement result on the R&S FSW for one of the 1 GHz sweep segments. The total aquisition time for all FFTs in this frequency range is about 300 ms (compared to 20 s on the R&S FSU). This is an important part of the improvement in test speed. The following plot shows the result of the sweep speed test, that includes the processing time and data transfer to the controller.
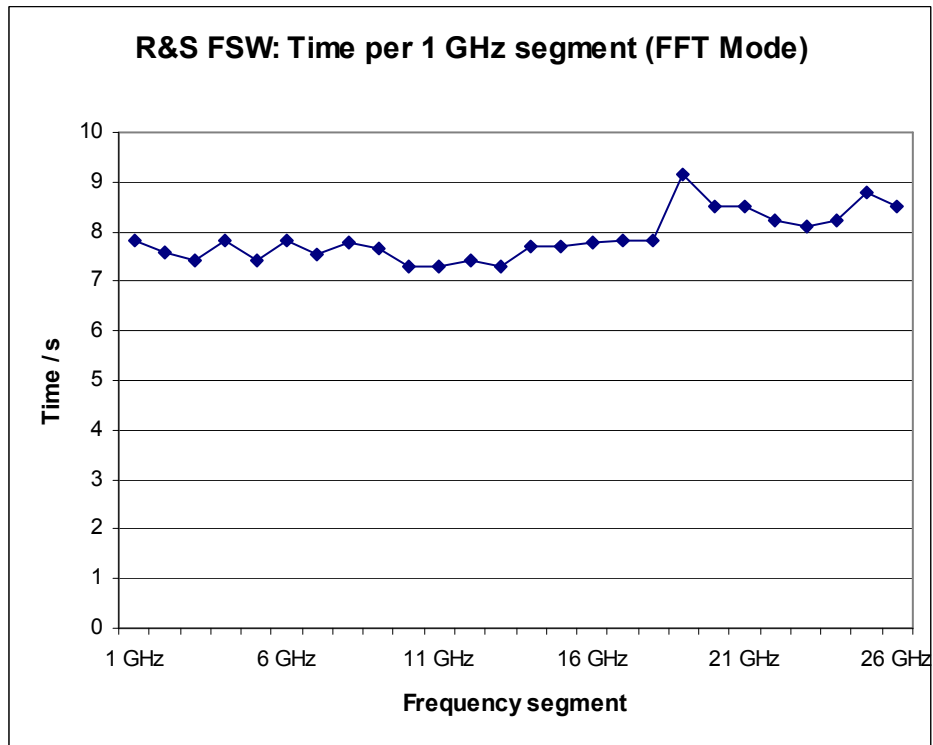
**R&S FSW: Time per 1 GHz segment (FFT Mode)**

*Figure 8: Total measurement time per 1 GHz span for the R&S FSW spectrum analyzer (RBW = 1 kHz)*

Figure 8 shows the result of a measurement performed on the R&S FSW in FFT mode. All other settings are equal to the measurement performed with the R&S FSU. The R&S FSW performs the FFT processing over a much wider capture bandwidth, using a wide channel filter in front of the A/D converter. The data aquisition time for this measurement is arround 300 ms seconds as shown in the screen copy, the total time for each FFT sweep over 1 GHz is about 8 seconds. The slight increase in the total measurement time above 18 GHz in each segment is due to the down-converter concept in the R&S FSW. The first local oscillator is doubled for frequencies above 18 GHz. Due to the stepped sweep and doubling process, an additional FFT is required to realize the 1 GHz span that is used in the setup. As each FFT will require about 300 ms aquisition time plus processing time, this results in a small increase for the segment.

The total time across a frequency range up to 26 GHz is only 3.5 minutes.

- R&S FSU: Span 26 GHz, RBW 1kHz, FFT Filter    27 min (60 s / GHz)
- R&S FSW: Span 26 GHz, RBW 1kHz, FFT Filter:  3.5 min (8 s / GHz

Improvement:  The R&S FSW is about 8 times faster than the R&S FSU.

# 5 Conclusion

Fast measurements are very important for many applications. Especially spurious measurements with very low level limits have been a time-consuming task in the past. Modern wideband signal- and spectrum analyzers offer a tremendous improvement of measurement speed for low level spurious emissions. The full digital IF processing in combination with a fast Fourier transformation (FFT) analysis provide great speed improvements compared to a digital implementation of a swept IF. Especially an architecture with a wide capture bandwidth together with a powerful signal processing like in the R&S FSW can save a lot of measurement time.

Compared to previous generations of digital spectrum analyzers, the speed improvement of the FSW can make measurements with small RBW more than hundred times faster than before.

# 6 Ordering Information

| | | |
|---|---|---|
| R&S FSU3 | Spectrum analyzer 20 Hz to 3.6 GHz | 1313.9000.03 |
| R&S FSU8 | Spectrum analyzer 20 Hz to 8 GHz | 1313.9000.08 |
| R&S FSU26 | Spectrum analyzer 20 Hz to 26.5 GHz | 1313.9000.26 |
| R&S FSU43 | Spectrum analyzer 20 Hz to 43 GHz | 1313.9000.43 |
| R&S FSU50 | Spectrum analyzer 20 Hz to 50 GHz | 1313.9000.50 |
| R&S FSU67 | Spectrum analyzer 20 Hz to 67 GHz | 1313.9000.67 |
| R&S FSV3 | Signal- and Spectrum analyzer 10 Hz to 3.6 GHz | 1307.9002.03 |
| R&S FSV7 | Signal- and Spectrum analyzer 10 Hz to 7 GHz | 1307.9002.07 |
| R&S FSV13 | Signal- and Spectrum analyzer 10 Hz to 13.6 GHz | 1307.9002.13 |
| R&S FSV30 | Signal- and Spectrum analyzer 10 Hz to 30 GHz | 1307.9002.30 |
| R&S FSV40 | Signal- and Spectrum analyzer 10 Hz to 40 GHz | 1307.9002.40 |
| R&S FSW8 | Signal- and Spectrum analyzer 2 Hz to 8 GHz | 1312.8000.08 |
| R&S FSW13 | Signal- and Spectrum analyzer 2 Hz to 13.6 GHz | 1312.8000.13 |
| R&S FSW26 | Signal- and Spectrum analyzer 2 Hz to 26.5 GHz | 1312.8000.26 |

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