Realtime FFT processing in Rohde & Schwarz receivers

Radiomonitoring & Radiolocation
Application Brochure | 01.00

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Rohde & Schwarz receivers

ROHDE&SCHWARZ

Introduction

This application brochure describes the sophisticated digital signal processing implemented in all modern Rohde & Schwarz receivers. The implementation is optimized for applications such as detecting unknown signals, identifying interference, spectrum monitoring, spectrum clearance, signal search over wide frequency ranges, producing signal content and direction finding of identified signals. The advantages of digital signal processing for radiomonitoring operators in their daily work are also explained.

Products from Rohde & Schwarz

- R&S®PR100 portable receiver
- R&S®EM100 digital compact receiver
- R&S®EB500 monitoring receiver
- R&S®EB510 HF monitoring receiver
- R&S®ESMD wideband monitoring receiver
- R&S®DDF007 compact direction finder
- R&S®DDF205 digital direction finder
- R&S®DDF255 digital direction finder

State-of-the-art design of frontend and digital signal processing modules is the key to monitoring receiver efficiency and performance. Rohde & Schwarz monitoring receivers are optimized specifically for spectrum monitoring and interference hunting applications. Typically, they are used for the following tasks:

- Fast detection of unknown signals
- Search for activities over wide frequency ranges
- Monitoring of individual frequencies, lists of frequencies or frequency ranges
- Measurement of spectral characteristics of very short or rarely occurring signals
- Storage of activities
- Triggering of further activities after a signal is detected
- Demodulation of communications and/or transfer of demodulated signals for processing
- Integration into civil and military dedicated systems
- Homing, i.e. localization of signal sources and direction finding
- Simple coverage measurements
- Measurements in line with ITU recommendations

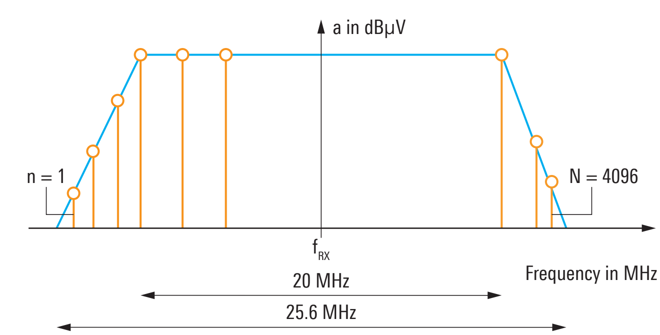
These tasks place special requirements on the receivers' hardware and software, the type of control via front panel or remote control interface, the provision and processing of captured data, and the receivers' integration into complex systems. Radiomonitoring receivers must be able to process antenna signals with high cumulative loads and wide dynamic range. In particular, seamless (gapless) real-time processing is a requirement that other receiver types usually do not meet.

Digital signal processing

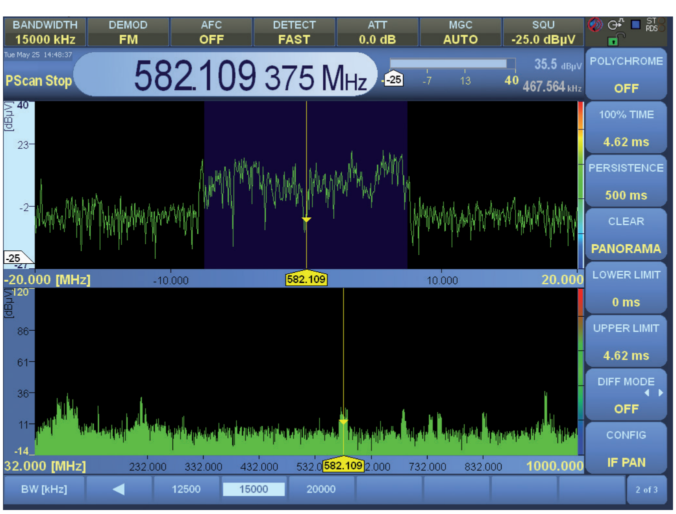
Unknown signals are normally detected by performing high-speed scans over wide frequency ranges, and then analyzed in detail in fixed frequency mode. A radiomonitoring receiver's scan speed and probability of intercept (POI) are determined by its realtime bandwidth, sensitivity and the type and speed of signal processing employed.

To provide high realtime bandwidth without compromising sensitivity and dynamic range, some Rohde & Schwarz radiomonitoring receivers feature multiple, switchable broadband receive paths (e.g. 20 MHz/80 MHz path in the R&S®ESMD). Multifunctional IF panorama displays with a wide range of setting functions are available in addition to allow powerful, in-depth analysis of detected signals.

Signal processing for IF spectrum



Actual sampling bandwidth compared with selected IF bandwidth



IF spectrum, with selected demodulation bandwidth highlighted in blue. Lower part: panorama scan.

High receiver sensitivity, high signal resolution

In the following, the special aspects regarding sensitivity and signal resolution in radiomonitoring receivers are explained, assuming an IF bandwidth (realtime bandwidth) of 20 MHz as an example.

Even very short signal pulses can be captured since the receiver displays the wide bandwidth of 20 MHz in a single spectrum around the set center frequency without any scanning being required.

The receiver's IF spectrum is digitally calculated using fast Fourier transform (FFT). The use of FFT computation at the IF offers a major advantage: The receiver sensitivity and signal resolution are clearly superior to those of a conventional analog receiver at the same spectral display width.

IF spectrum

FFT calculation of the IF spectrum is performed in a number of steps. These are described in simplified form for an IF bandwidth of 20 MHz ($BW_{IF\ spectrum}$ = 20 MHz), which yields high spectral display.

Due to the finite edge steepness of the IF filter, the sampling rate f_s must be larger than the selected IF bandwidth $BW_{IF\ spectrum}$. The quotient of the sampling rate and the IF bandwidth is > 1 and is a measure of the edge steepness of the IF filter. This relationship is expressed by the following two formulas (for the AUTO setting):

$$\frac{f_s}{BW_{IF\ spectrum}} = \text{const}$$

or

$$f_S = BW_{IF\ spectrum} \times \text{const}$$

The value of the constant is dependent on the selected IF bandwidth, i.e. it varies as a function of the IF bandwidth.

For an IF bandwidth of $BW_{IF\ spectrum}$ = 20 MHz, the constant has a value of 1.28. Therefore, to display a 20 MHz IF spectrum, a sampling rate of f_S = 25.6 MHz is required.

The described receiver uses a maximum FFT length N of 4096 points to generate the IF spectrum. To calculate these points, the 25.6 MHz sampling band in the above example is divided into 4096 equidistant frequency slices, which are also referred to as "bins" (see figure "Signal processing for IF spectrum").

The bandwidth BW_{bin} of the frequency slices is obtained as follows:

$$BW_{bin} = \frac{f_s}{4096} = \frac{25.6\text{ MHz}}{4096} = 6.25\text{ kHz}$$

This means that in the above example only the calculated bandwidth of 6.25 kHz for each bin has to be taken into account as the noise bandwidth in the calculation of the displayed noise level (DNL) in accordance with the formula below (the effect of the window function (Blackman window) of the FFT is not considered here for simplicity's sake):

$$DNL = -174\text{ dBm} + NF + 10 \times \log(BW_{bin}/\text{Hz})$$

The quantity NF represents the overall noise figure of the receiver.

The above example shows that, due to the use of the FFT, the actual resolution bandwidth (RBW) to be taken into account in DNL calculation is clearly smaller (i.e. BW_{bin}) than would be expected for the wide (unscanned) display range of 20 MHz.

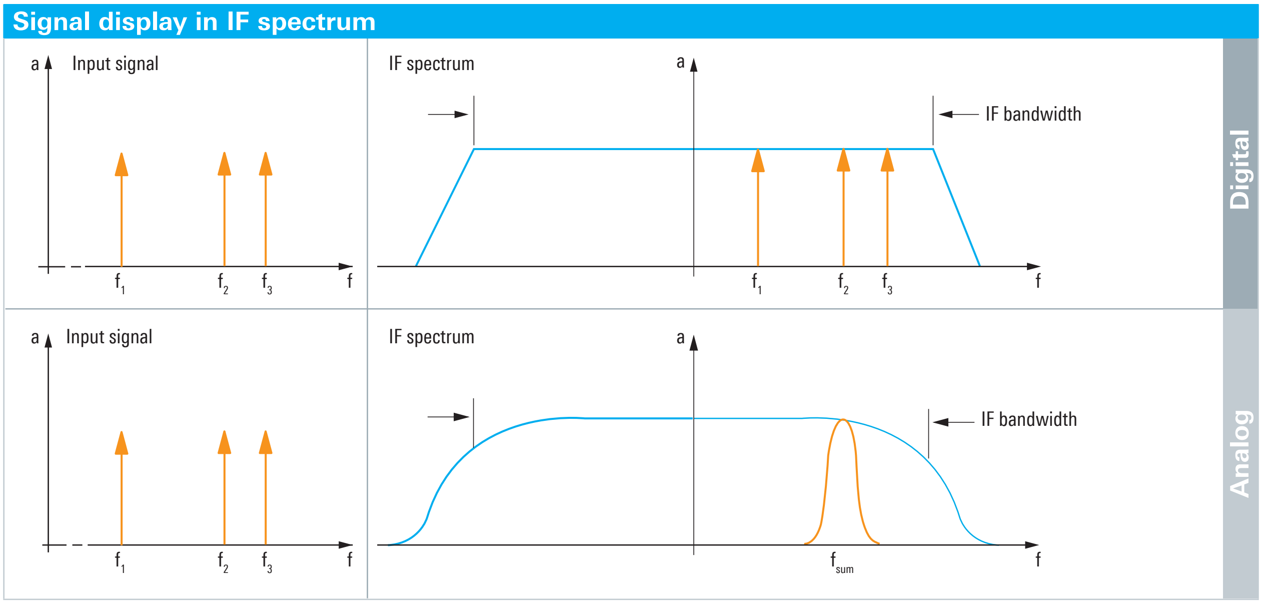
Another advantage of the high spectral resolution used in the FFT calculation is that signals located close together (e.g. f_1, f_2 and f_3) can be captured and represented in the IF spectrum as discrete signals (see figure "Signal display in IF spectrum").

If, on an analog receiver, a resolution bandwidth equal to the set IF bandwidth were selected ($RBW = BW_{IF\ spectrum}$), a sum signal f_{sum} would be displayed instead of the three discrete signals f_1, f_2 and f_3.

The FFT resolution can also be selected manually. This offers the advantage that the FFT resolution can be chosen to precisely match the channel spacing of the radio service to be analyzed. This ensures that the receiver will always be tuned to the center frequency of the channel in question. The channel spacings of all known radio services can be used as FFT resolutions, with the FFT length varying between 16 and 4096 points.

High-end radiomonitoring receivers feature DSP computing power so high that up to four times the number of FFT points actually needed is available, depending on the selected realtime bandwidth. By selecting an appropriate FFT length, even closely spaced channels can be reliably detected as discrete channels. By utilizing the higher number of FFT points available, the FFT can be expanded by up to four times. The high computing power can also be used to perform FFT calculation using overlapping windows. This makes even short pulses clearly discernible in the spectrum's waterfall display.

Signal display in IF spectrum



Signal resolution in IF spectrum in digital and analog receiver concept.

Realtime capability

To provide a measure of the realtime capability of radiomonitoring receivers, a virtual scan speed is often specified. This figure designates the scan speed in scan ranges that are smaller than the receiver's maximum realtime bandwidth. Scans across this range can also be designated as realtime scans since the tuning time of the synthesizer can be ignored within the realtime bandwidth of the receiver. At a fixed frequency resolution and a sufficiently large realtime bandwidth, the speed of the realtime scan is determined solely by the receiver's computing power (see table).

When it comes to assessing a receiver's realtime capability with respect to signal processing, seamless data acquisition is the key criterion. While some "realtime receivers" are able to capture a spectrum in realtime for a specific period of time, they do not offer sufficient processing resources to continue data acquisition without interruptions, i.e. seamlessly. Instead, data has to be buffered, and signal acquisition is interrupted in order to process and display the buffered data.

By contrast, Rohde & Schwarz radiomonitoring receivers offer high-speed processing that permits the seamless capturing and processing of signals in realtime (no buffering needed).

For the following description, an IF bandwidth of 10 MHz is assumed. At this bandwidth, 12.8 Msample are collected per second.

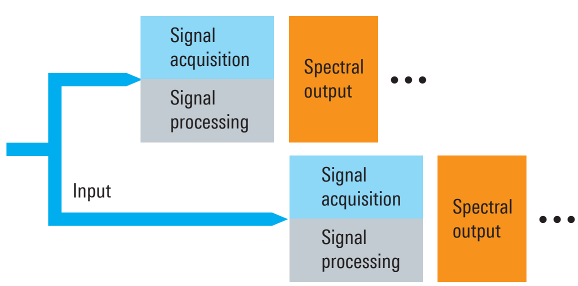
An FFT with 2048 points processes 2048 samples per frame. Consequently, 6250 FFTs are required in order to process one second of the incoming data stream. Each individual FFT therefore includes samples received during a period of 1 s/6250, which is 160 µs.

Internal computing power of the R&S®ESMD

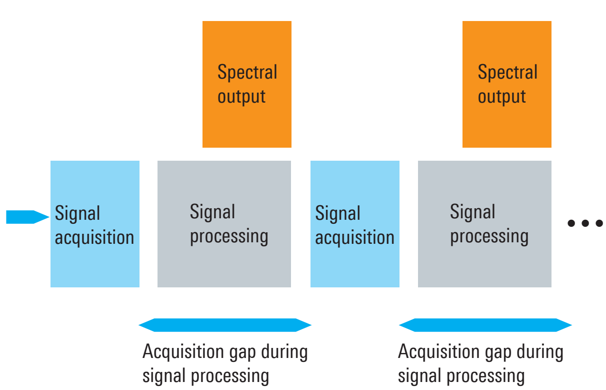
Frequency resolution in kHz	80 MHz realtime bandwidth	
	Spectra per second	**Time resolution in µs**
25	25 000	40
50	50 000	20
100	100 000	10
500	500 000	2
2000	2 000 000	0.5

Signal processing

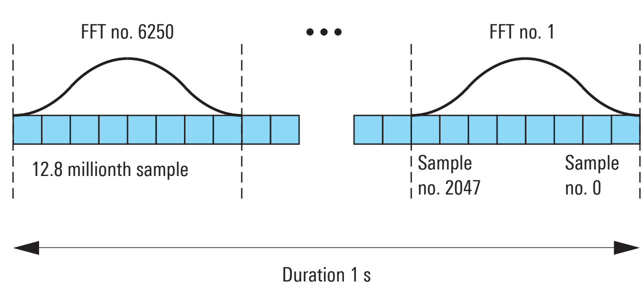
Seamless (gapless) signal acquisition



Signal acquisition with gaps



Number of samples and FFTs per second for a 10 MHz IF bandwidth



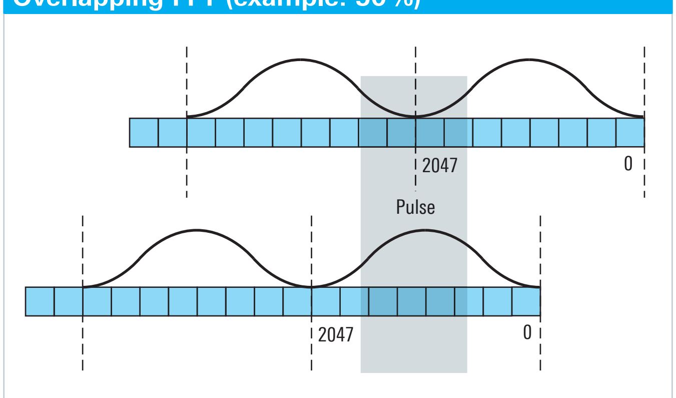
The Blackman filter indicated in the bottom right figure is needed to avoid artificially created spectral components that would arise when different signal levels occur in the first and last sample. However, a sometimes substantial attenuation has to be accepted for signals that are shorter than the duration of an FFT frame and located at the boundary between two frames.

To capture a signal with 100 % reliability and correctly measure its level, a minimum signal duration corresponding to two FFT frames, i.e. 320 µs in this example, would be required. If the focus is on detecting a signal rather than measuring its level correctly, considerably shorter pulses down to several hundred nanoseconds can be captured and processed. This type of processing is generally referred to as seamless (gapless), although pulses may go undetected if they are very short and located at an unfavorable position with respect to the FFT frame (see upper processing step in the figure “Overlapping FFT“). Therefore, some Rohde & Schwarz receivers offer overlapping FFT. Two FFTs whose frames are shifted with respect to one another are calculated in parallel from the data stream. A sample located in the minimum of the Blackman filter curve of one FFT will then be found in the maximum of the other.

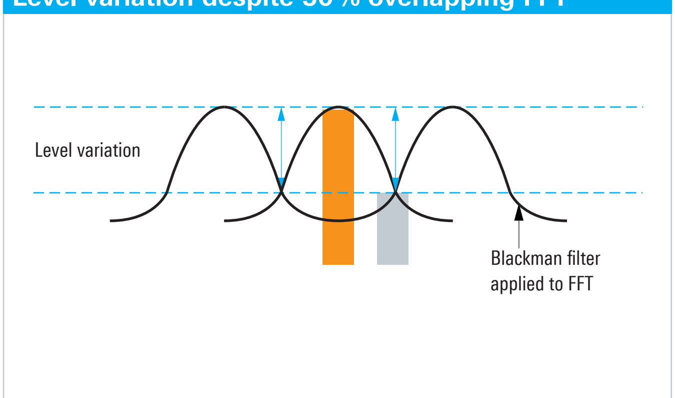
For a realtime bandwidth of 10 MHz as used in this example, a minimum signal duration of 240 µs is required to ensure 100 % reliable signal acquisition and correct level measurement. For shorter pulses, the level may not be displayed correctly, but only very weak signals may go undetected.

It is evident that the use of digital signal processing in a radiomonitoring receiver offers great advantages. Extremely high sensitivity (due to very fine resolution) combines with a broad spectral overview and high scan speed to significantly increase the probability of intercept over analog receivers or spectrum analyzers.

Overlapping FFT (example: 50 %)



Level variation despite 50 % overlapping FFT



Fast spectral scan

In the panorama scan mode, the spectrum is displayed across a frequency range far wider than the radiomonitoring receiver's realtime bandwidth. This mode provides users with a quick overview of the spectrum occupancy.

The principle of the fast spectral scan (panorama scan) is described in the following using a receiver with up to 20 MHz realtime bandwidth (such as the R&S®EB500). During the scan, frequency windows of max. 20 MHz width are linked in succession, so that the complete, predefined scan range is traversed (see figure "Signal processing in panorama scan mode"). As is done for the IF spectrum, an FFT is used to process the broad window with a finer resolution.

The width of the frequency window and the FFT length (number of FFT points) are variable and are selected by the receiver automatically.

The user can select among 24 resolution bandwidths from 100 Hz to 2 MHz. The resolution bandwidth corresponds to the width of the frequency slices (bin width) mentioned under "IF spectrum". Based on the selected bin width and start and stop frequency, the monitoring receiver automatically determines the required FFT length and the width of the frequency window for each scan step. The receiver selects these internal parameters so that the optimum scan speed is achieved for each resolution bandwidth (see figure "Resolution in panorama scan mode").

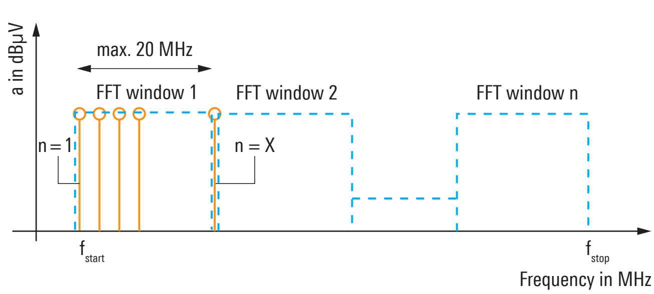
The highest resolution bandwidth of 2 MHz yields the maximum scan speed, while the smallest resolution bandwidth of 100 Hz yields maximum sensitivity.

The resolution bandwidth (bin width) for the panorama scan (selectable between 100 Hz and 2 MHz) therefore corresponds to the resolution bandwidth (BW_{bin}) used in the DNL calculation for the IF spectrum (see DNL formula under "IF spectrum"), and can be used for calculating the DNL for the panorama scan. Moreover, the user selects the resolution bandwidth to obtain the desired frequency resolution (see figure "Bin width and channel spacing").

A receiver's available IF bandwidth has a direct influence on the achievable panorama scan speed. Doubling the IF bandwidth (i.e. using 20 MHz instead of 10 MHz in this example) will also double the achievable scan speed. If the IF bandwidth is increased from 20 MHz to 80 MHz, the scan speed can be boosted by a factor of four.

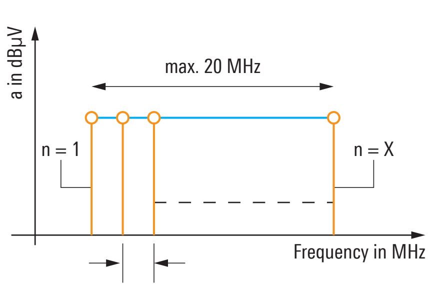
The above explanations show that the use of digital signal processing in a radiomonitoring receiver offers decisive advantages. Extremely high sensitivity (due to very fine resolution) combined with a broad spectral overview and maximum scan speed significantly increases the probability of intercept as compared with an analog receiver.

Signal processing in panorama scan mode



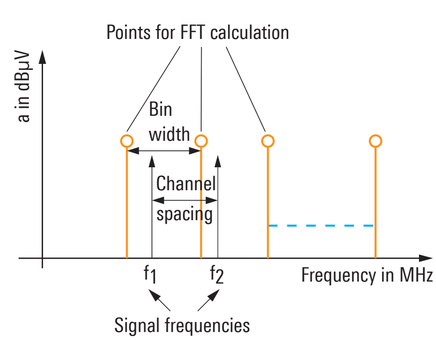
Basic sequence of steps in fast panorama scan mode

Resolution in panorama scan mode



Selecting the panorama scan resolution by varying the bin width

Bin width and channel spacing



Selecting a 12.5 kHz bin width to capture a radio service using 12.5 kHz channel spacing

Service you can rely on

- Worldwide
- Local and personalized
- Customized and flexible
- Uncompromising quality
- Long-term dependability

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

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