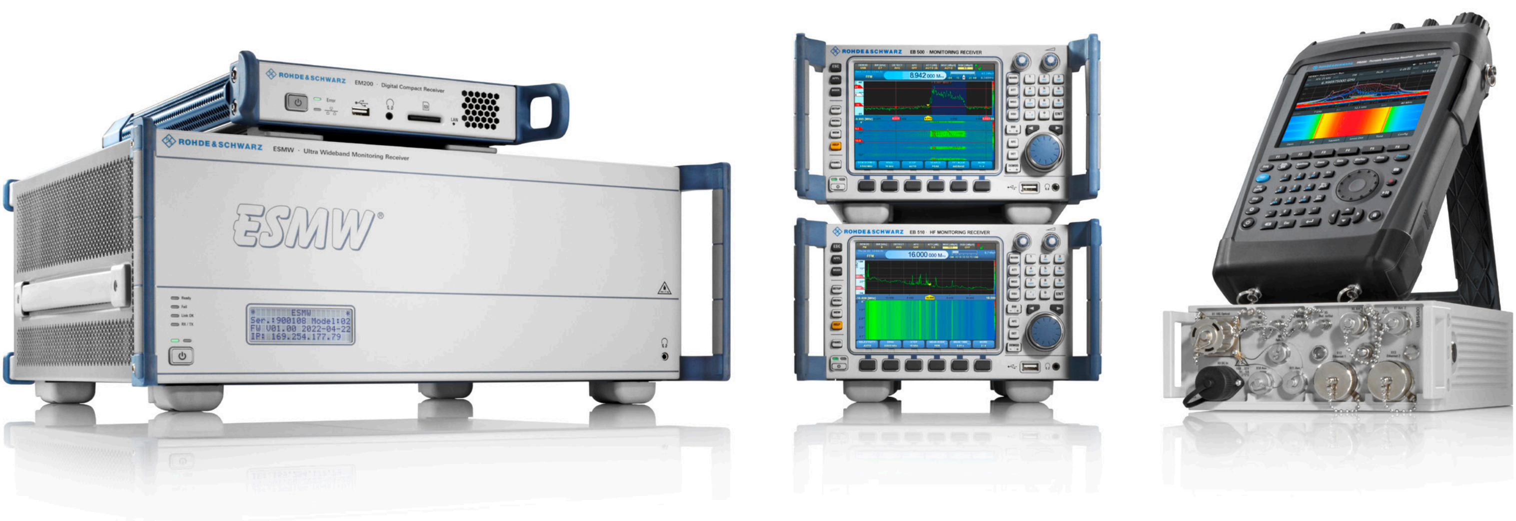
# REAL-TIME FFT PROCESSING IN ROHDE & SCHWARZ RECEIVERS




Application Brochure
Version 02.00

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# INTRODUCTION

This application brochure describes the sophisticated digital signal processing available in all modern Rohde & Schwarz receivers. The signal processing is optimized for a detecting unknown signals, identifying interference, spectrum monitoring, spectrum clearance, signal searches over wide frequency ranges, signal content production and direction finding. The daily benefits of digital signal processing for radiomonitoring operators are also explained.

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

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

The tasks place demanding requirements on receiver hardware and software. Some modules are controlled via a front panel or remote control interface while providing and processing captured data and integrate receivers into complex systems. Radiomonitoring receivers must process antenna signals with high cumulative loads and a wide dynamic range. In particular, seamless (gapless) realtime processing is a requirement that other receiver types often fail to meet.

## PRODUCTS FROM ROHDE & SCHWARZ

- R&S®PR200 portable monitoring receiver
- R&S®EM200 digital compact receiver
- R&S®UMS400 universal monitoring system
- R&S®EB500 monitoring receiver
- R&S®EB510 HF monitoring receiver
- R&S®UMS300 universal monitoring system
- R&S®ESMD wideband monitoring receiver
- R&S®ESME wideband monitoring receiver
- R&S®ESMW ultra wideband monitoring receiver

# DIGITAL SIGNAL PROCESSING

Unknown signals are normally detected with high-speed scans over wide frequency ranges and then analyzed in detail in fixed frequency mode. The scan speed and probability of intercept (POI) for a radiomonitoring receiver are determined by its real-time bandwidth, sensitivity and the type and speed of signal processing.

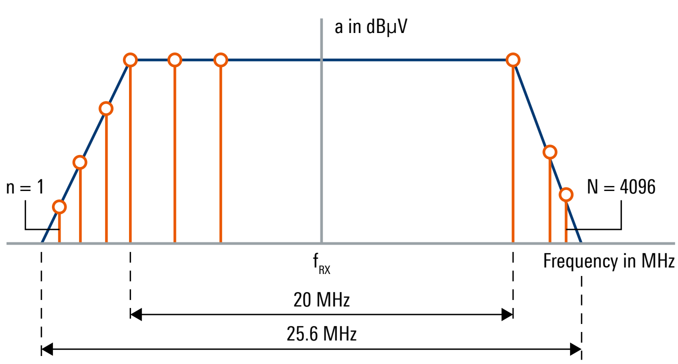
Some Rohde & Schwarz radiomonitoring receivers feature multiple, switchable broadband receive paths (e.g. 20 MHz/80 MHz path in the R&S®ESMD) for high real-time bandwidth without compromising sensitivity and dynamic range. Multifunctional IF panorama displays with a wide range of settings are also available for powerful, in-depth analysis of detected signals.

### High receiver sensitivity, high signal resolution

The following explains special aspects of sensitivity and signal resolution in radiomonitoring receivers, for assumed IF bandwidth (real-time bandwidth) of 20 MHz.

### Signal processing for IF spectrum

Actual sampling bandwidth compared with selected IF bandwidth




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

The receiver IF spectrum is digitally calculated using fast Fourier transform (FFT). Using FFT calculations at the IF has some major benefits. The receiver sensitivity and signal resolution are superior to conventional analog receivers while maintaining the same spectral display width.

### IF spectrum

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

The finite edge steepness of the IF filter requires the sampling rate $f_S$ be larger than the IF bandwidth $BW_{IF\ spectrum}$. The quotient for the sampling rate and IF bandwidth are > 1 and is a measure of the edge steepness of the IF filter. This relationship is expressed by the following (for the AUTO setting):

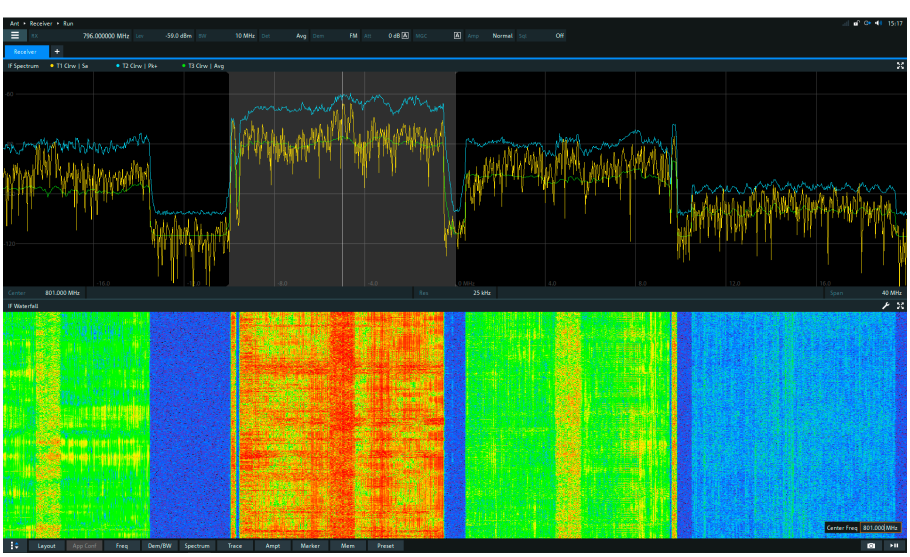
$$\frac{f_s}{BW_{IF\ spectrum}} = const$$

or

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

The value of the constant depends on the selected IF bandwidth, which 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. Displaying a 20 MHz IF spectrum requires a sampling rate of $f_S$ = 25.6 MHz.



IF spectrum, with selected demodulation bandwidth highlighted in gray.

The 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 example is divided into 4096 equidistant frequency slices or bins (see: Signal processing for IF spectrum).

Bandwidth $BW_{bin}$ for the frequency slices is obtained as follows:

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

In the example, only the calculated bandwidth of 6.25 kHz for each bin is included as noise bandwidth when calculating the displayed noise level (DNL) in line with the formula below (the effect of the FFT Blackman window function is not included):

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

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

The example above shows that using FFT makes the actual resolution bandwidth (RBW) in the DNL calculation 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 in the FFT calculation is the capture of signals located close together ($f_1$, $f_2$ and $f_3$) and their representation in the IF spectrum as discrete signals (see: Signal display in IF spectrum).

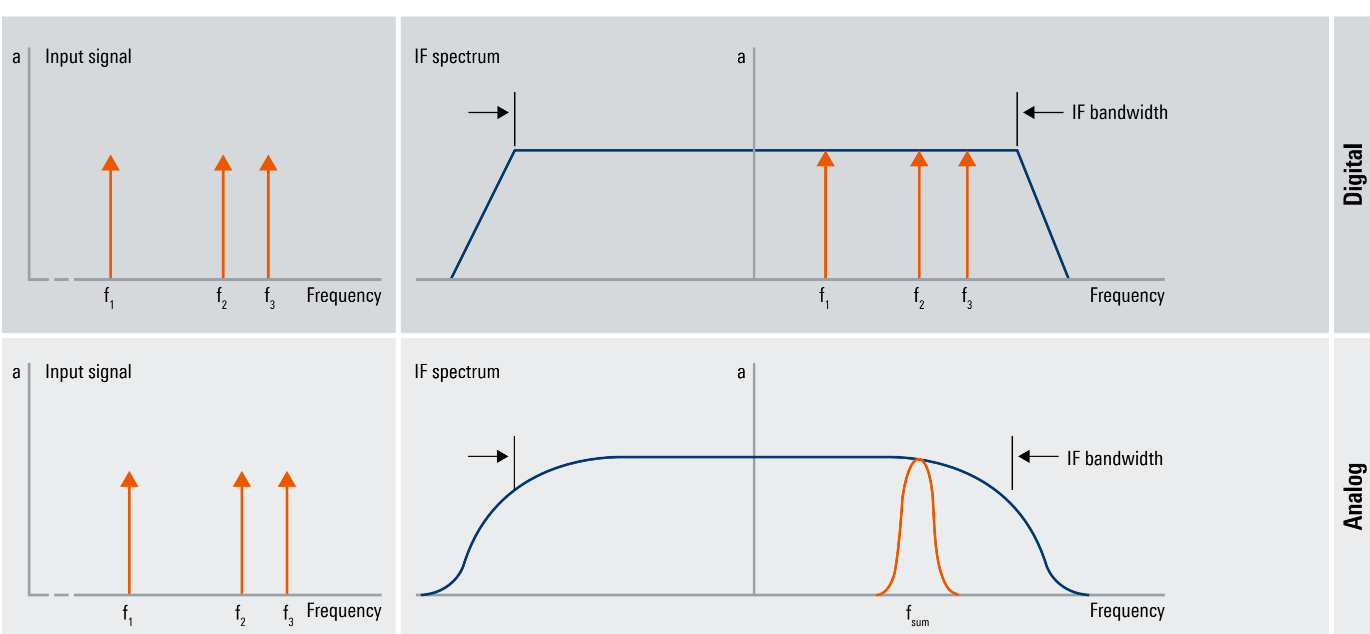
If the resolution bandwidth equal to the set IF bandwidth is selected ($RBW = BW_{IF\ spectrum}$) on an analog receiver, a sum signal $f_{sum}$ would be displayed instead of the three discrete signals $f_1$, $f_2$ and $f_3$.

The FFT resolution can also be selected manually and the FFT resolution will precisely match the channel spacing of the radio service to be analyzed. The receiver is then always 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 have DSP computing power so high that up to four times the number of FFT points actually needed is available, depending on the selected real-time 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 calculations with overlapping windows. This makes even short pulses clearly discernible in the spectrum waterfall display.

## Signal display in IF spectrum

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



# REAL-TIME CAPABILITY

A virtual scan speed is often specified to measure the real-time capability of radiomonitoring receivers. The figure designates the scan speed in ranges smaller than the maximum real-time receiver bandwidth. Scans across this range can also be called real-time scans, since the tuning time for the synthesizer can be ignored within the real-time receiver bandwidth. At a fixed frequency resolution and with sufficiently large real-time bandwidth, the speed of the real-time scan is determined solely by the receiver's computing power (see table).

When assessing a receiver's real-time signal processing capabilities, seamless data acquisition is key. While some real-time receivers can capture a spectrum in real time for a specific period, they do not have enough processing resources to continue data acquisition without interruption. Data is buffered instead and signal acquisition is interrupted to process and displays the buffered data.

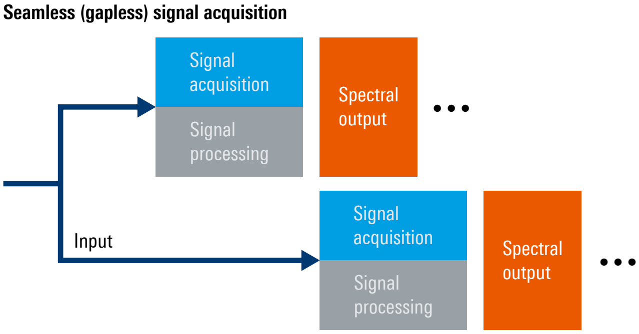
Rohde & Schwarz radiomonitoring receivers offer high-speed processing for the seamless capturing and processing of signals in real time (no buffering needed).

The following assumes an IF bandwidth of 10 MHz. At this bandwidth, 12.8 Msample are collected per second.

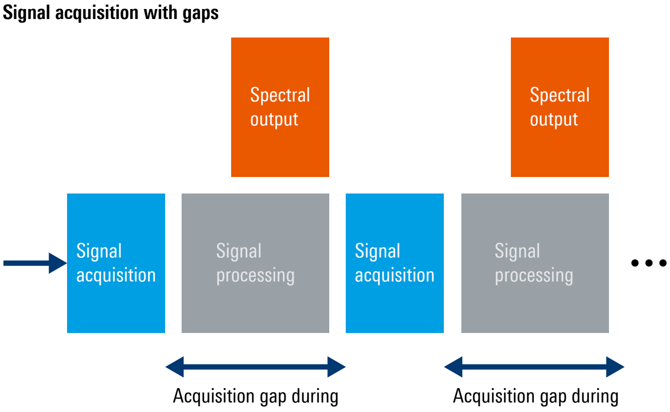
An FFT with 2048 points can process 2048 sample per frame. So, 6250 FFTs are required to process one second of an incoming data stream. Each individual FFT includes samples received during a period of 1 s/6250 or 160 µs.

## Signal processing

**Seamless (gapless) signal acquisition**



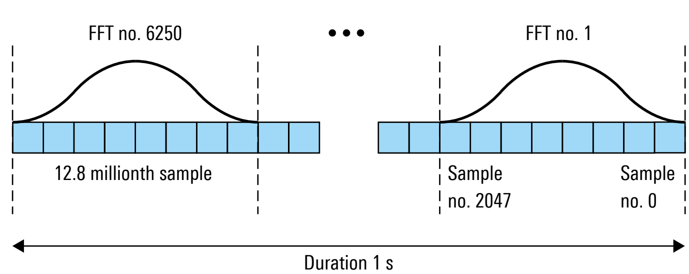

**Signal acquisition with gaps**




## 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 |

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



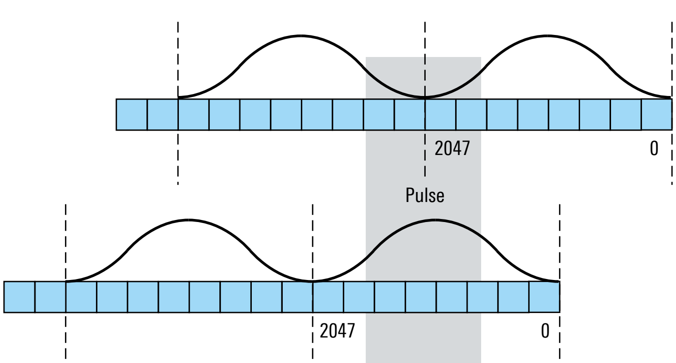
The Blackman filter in the bottom right figure is needed to avoid artificially created spectral components that arise with different signal levels in the first and last sample. However, sometimes substantial attenuation is needed for signals that last shorter than an FFT frame and are located at the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

To capture a signal with 100 % reliability and correctly measure its level, a minimum signal duration of two FFT frames or 320 µs is required. When detecting a signal is more important than correctly measuring its level, much shorter pulses down to several hundred nanoseconds can be captured and processed. Such processing is generally called seamless (or gapless), although pulses may go undetected if they are very short and located in an unfavorable position relative to the FFT frame (see: Upper processing step in the overlapping FFT). Some Rohde & Schwarz receivers have overlapping FFTs, where two FFTs with frames are shifted relative to one another and calculated in parallel from the data stream. A sample in the minimum of the Blackman filter curve of one FFT will then be in the maximum of the other.

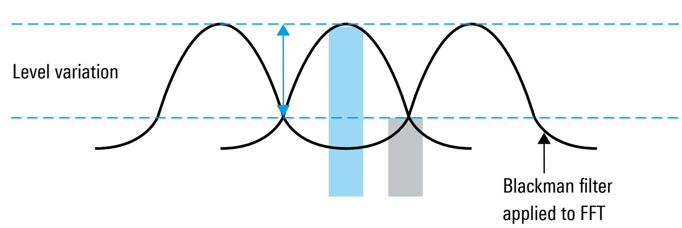
For the real-time bandwidth of 10 MHz in this example, a minimum signal duration of 240 µs is required to ensure 100 % reliable signal acquisition and correct level measurement. Shorter pulses may not have the level displayed correctly, but only very weak signals will go undetected.

Using digital signal processing in a radiomonitoring receiver offers obvious advantages. Extremely high sensitivity (very fine resolution) combined with a broad spectral overview and high scan speeds significantly increase the probability of intercept relative to analog receivers or spectrum analyzers.

**Overlapping FFT (example: 50 %)**




**Level variation despite 50 % overlapping FFT**

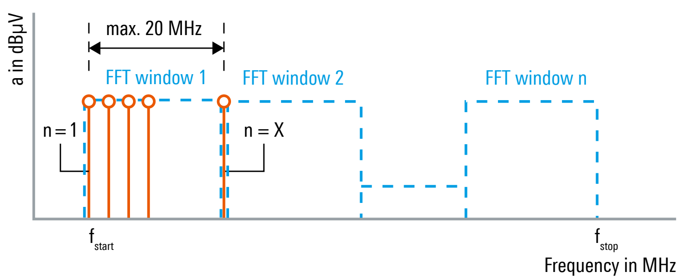


## Fast spectral scan

In the panorama scan mode, a spectrum is displayed across a frequency range far wider than the real-time receiver radiomonitoring bandwidth. The mode gives a quick overview of the spectrum occupancy.

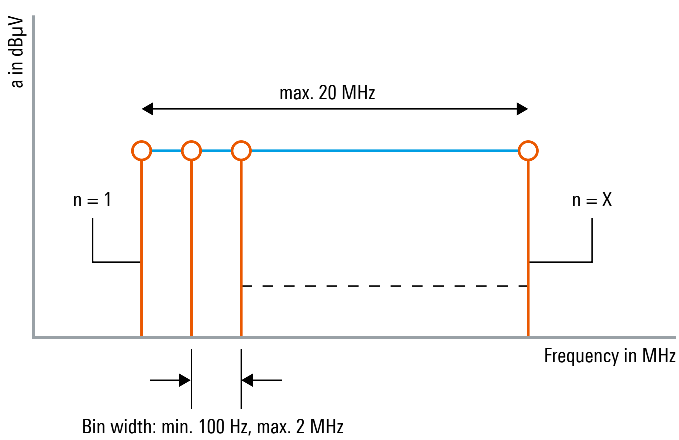
### Signal processing in panorama scan mode

Basic sequence of steps in fast panorama scan mode



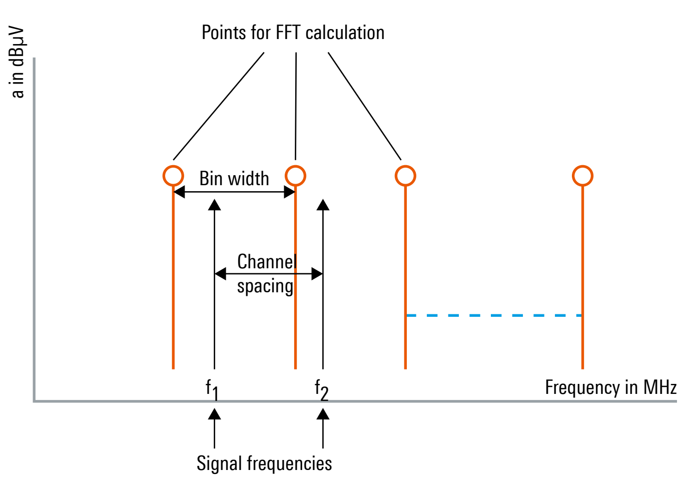

### Resolution in panorama scan mode

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




The principle of fast spectral scans (panorama scans) is described below using a receiver with up to 20 MHz real-time bandwidth (the R&S®EB500). During the scan, frequency windows of max. 20 MHz width are linked in succession to transverse the complete, predefined scan range is (see: Signal processing in panorama scan mode). As with the IF spectrum, FFTs process the broad window with finer resolution.

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

Users can choose from 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 for the optimum scan speed for each resolution bandwidth (see: 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) corresponds to the resolution bandwidth ($BW_{bin}$) used in the DNL calculation for the IF spectrum (see: DNL formula in the IF spectrum table) and can be used to calculate the DNL for the panorama scan. Users can also select the resolution bandwidth for the desired frequency resolution (see: Bin width and channel spacing).

The available receiver IF bandwidth has a direct influence on the maximum panorama scan speed. Doubling the IF bandwidth (using 20 MHz instead of 10 MHz) will also double the scan speed. If the IF bandwidth is increased from 20 MHz to 80 MHz, the scan speed can be quadrupled.

The explanations above show that digital signal processing in radiomonitoring receivers has clear benefits, including extremely high sensitivity (from very high resolution) combined with a broad spectral overview and maximum scan speed significantly increase the probability relative to analog receivers.

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