White Paper

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Understanding Key Real-Time Spectrum Analyzer Specifications

Spectrum analyzers are the fundamental instrument used by RF engineers to measure individual signals across a defined frequency band. They capture and display wanted and unwanted signals, enabling a range of measurements including power, frequency, modulation and distortion. There are several different types of spectrum analyzer system architectures. This paper will review the architecture of real-time spectrum analyzers (RTSA), swept-tuned spectrum analyzers, and vector signal analyzers, and highlight their relative merits and compromises.

Real-time spectrum analysis allows a spectrum analyzer to conduct continuous, gapless capture and analysis of elusive and transient signals, while conventional spectrum analyzers and vector signal analyzers do not have this capability due to their design. A swept-tuned spectrum analyzer scans the input by sweeping its local oscillator (LO) to down-convert the input frequency range to a fixed intermediate frequency (IF), which is then filtered by the resolution bandwidth (RBW) filter and detected. As the LO is swept, the input signal frequencies are effectively swept past the fixed frequency RBW filter. In effect, the spectrum analyzer can see only a small portion of the frequency span at any single moment, therefore the signal is visible only when it appears at the RBW filter at the right time and frequency. It is blind to transient signals that appear when the sweep is scanning a different part of the input frequency range (Figure 1).

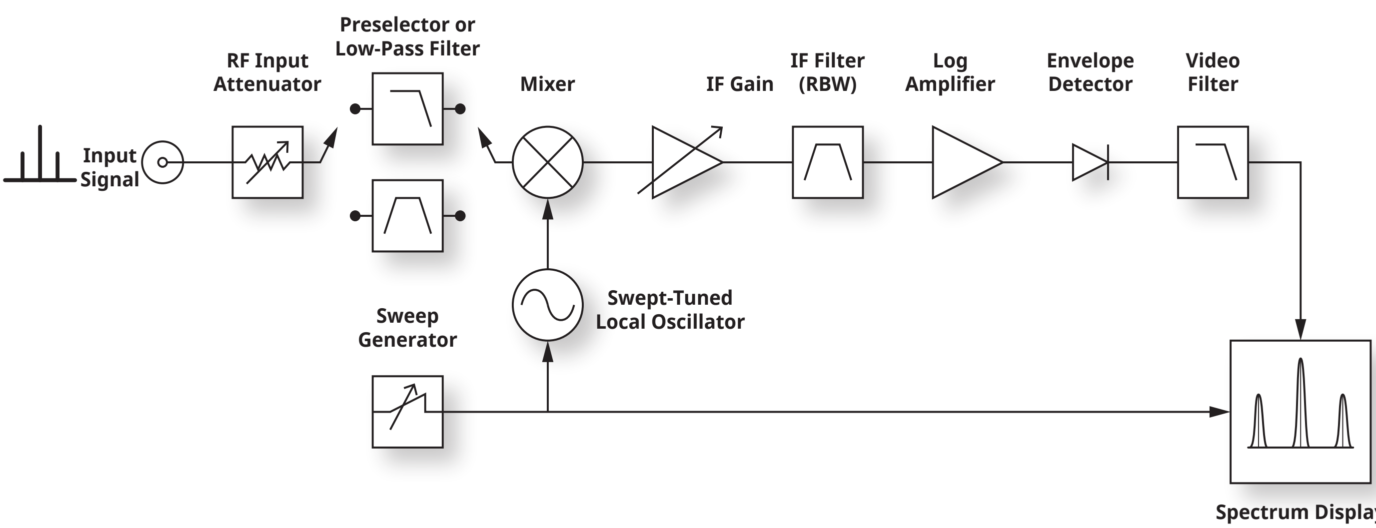

Figure 1. Diagram of a classic swept-tuned spectrum analyzer. In modern analyzers, the resolution bandwidth filtering and envelope detection and display are implemented using digital signal processing.

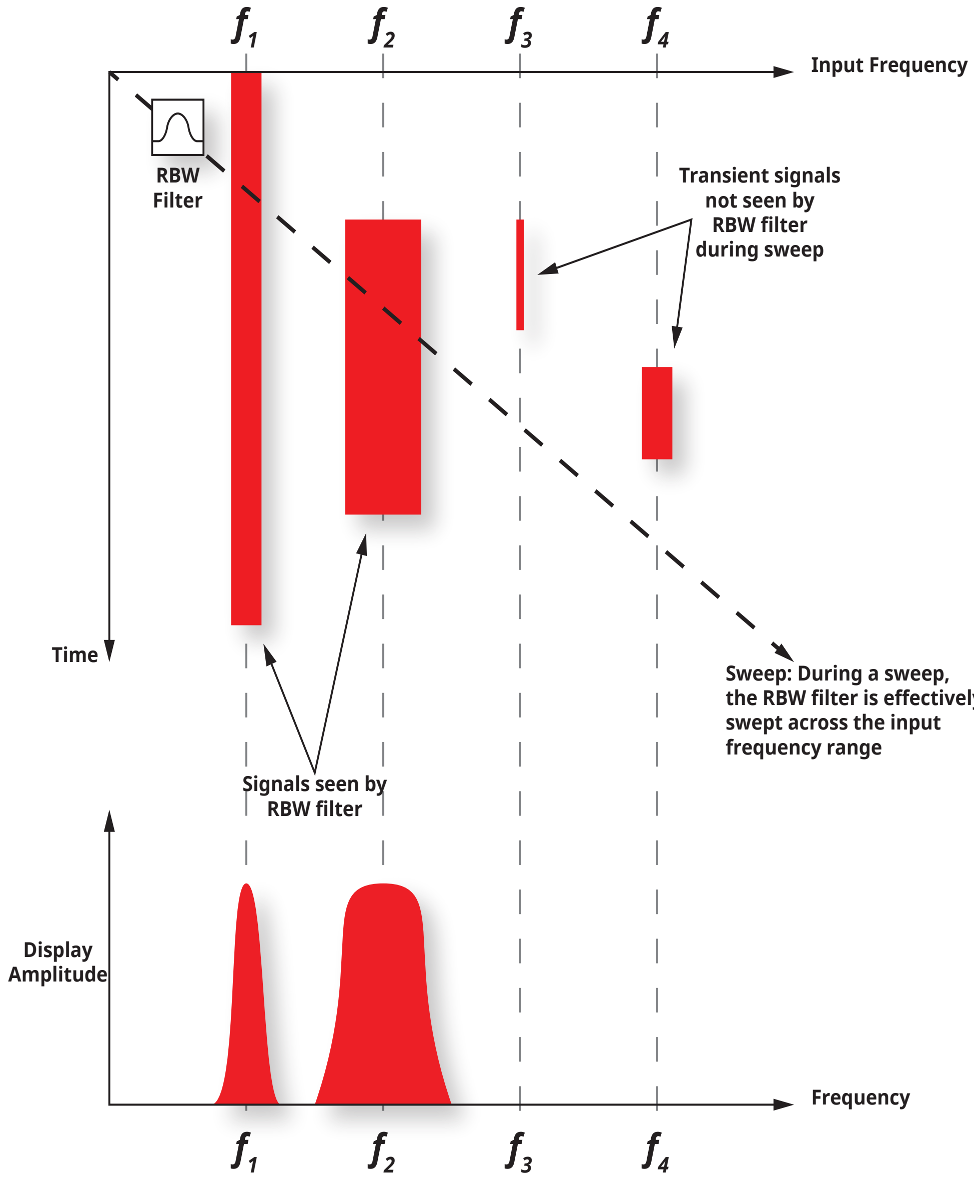

Figure 2. Swept-tuned spectrum analyzer response to transient signals during a sweep.

A vector signal analyzer down-converts the signal of interest within a certain bandwidth to a fixed frequency IF. The IF analog signal is sampled by an analog-to-digital converter (ADC) and a stream of time domain samples can be used for modulation domain analysis. For spectrum analysis, the time domain samples are transformed into a frequency domain spectrum using the fast Fourier transform (FFT). The FFT processes a block of samples, which will be referred to as a sample frame. The number of samples in the sample frame is referred to as the sample frame size or FFT size in this application note. When the FFT calculation is finished and the results are transferred to the display, the next sample frame is acquired. Although the LO is stationary, unlike the swept spectrum analyzer, the vector signal analyzer is blind to signal events occurring in the time gap between sample frames (Figure 2).

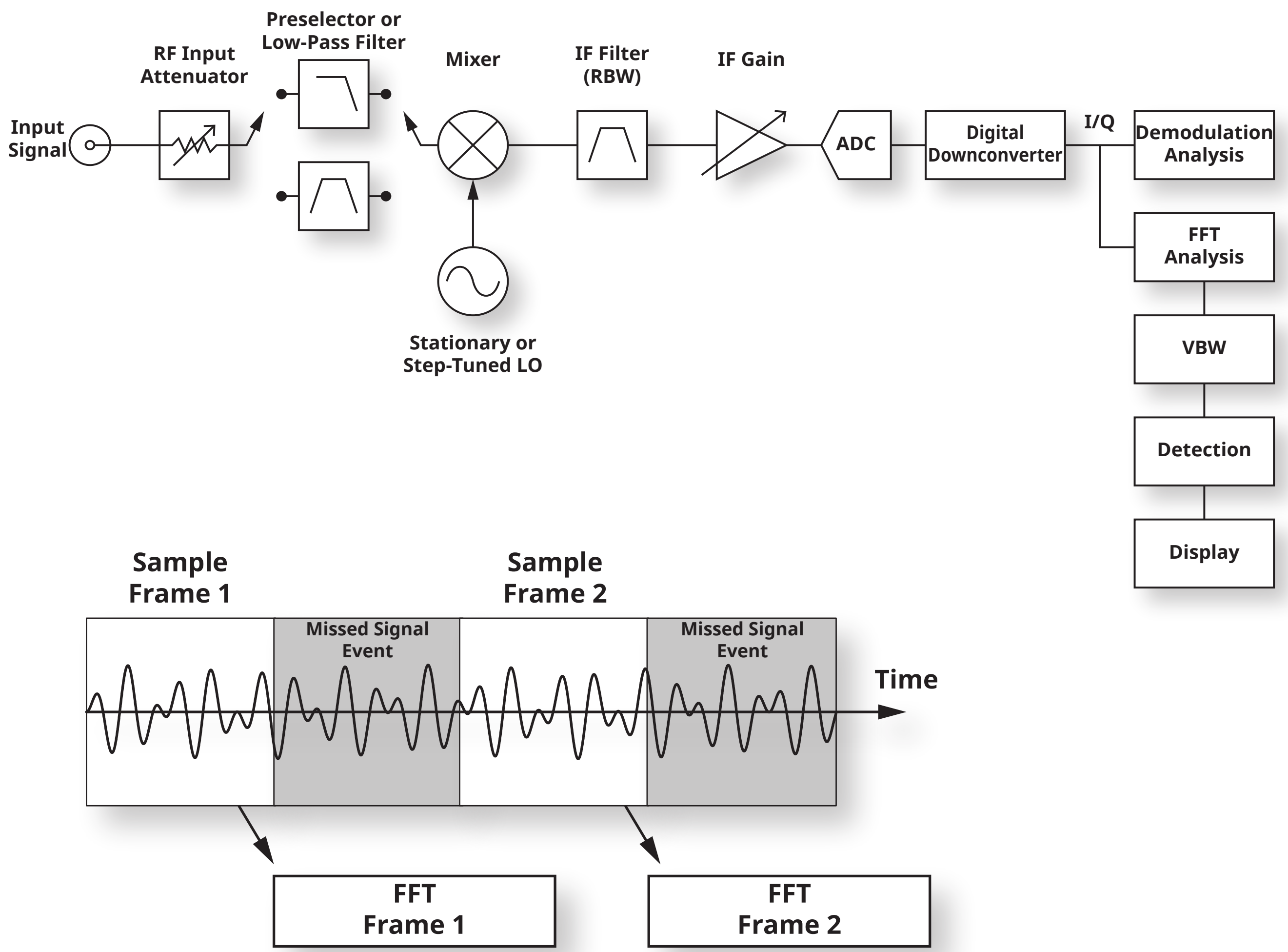

Figure 3. Block diagram of simplified vector signal analyzer and signal processing flow.

Nearly all modern spectrum analyzers combine the features of both the traditional swept spectrum analyzer and a vector signal analyzer. If the span is greater than the FFT analysis bandwidth, the LO will be stepped along to stitch together multiple FFTs to display a spectrum with the desired span. However, what sets an RTSA spectrum analyzer apart is its ability to continuously acquire samples of the signal and perform FFT analysis. Figure 3 illustrates the difference. Non-RTSA spectrum analyzers or vector signal analyzers using FFT analysis have a serial process flow to acquire samples and calculate the FFT. The RTSA process flow is parallel (Figure 4), in that it can acquire a new sample frame while simultaneously performing the FFT on the previous sample frame. This parallel processing requires fast digital hardware and a large memory buffer. RTSA spectrum analyzers, like Anritsu's Field Master Pro™ MS2090A solution, are capable of performing 527K FFTs per second for a 512 point FFT. The number of points of an FFT is the number of frequency points that span the FFT analysis bandwidth. It is also equal to the number of I/Q samples collected in a sample frame. The more points, the finer the frequency resolution, however, the FFT computation time increases.

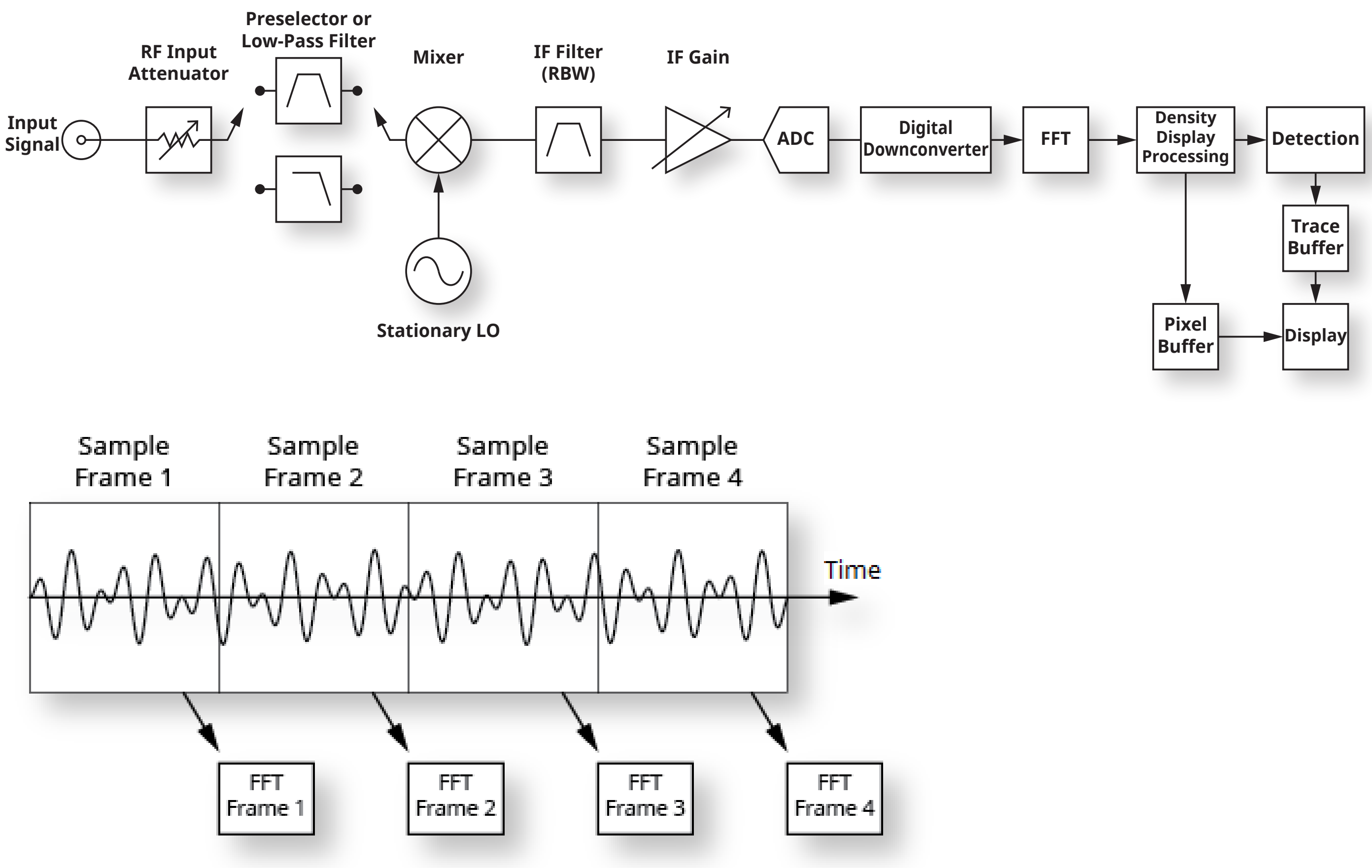

Figure 4. Real-time spectrum analyzer block diagram and signal processing flow.

The key performance metric is the probability of intercept (POI), defined as the minimum signal duration necessary to accurately measure the amplitude of a continuous wave (CW) signal. POI is affected by several factors: FFT processing speed, sample rate, window overlap, RBW, and span. The next section will explain the interdependence of these factors and their effect on POI.

Windowing

When a block of samples are acquired for FFT analysis, the mathematics of the FFT presumes the time domain signal is periodic with a period equal to the sample frame duration.

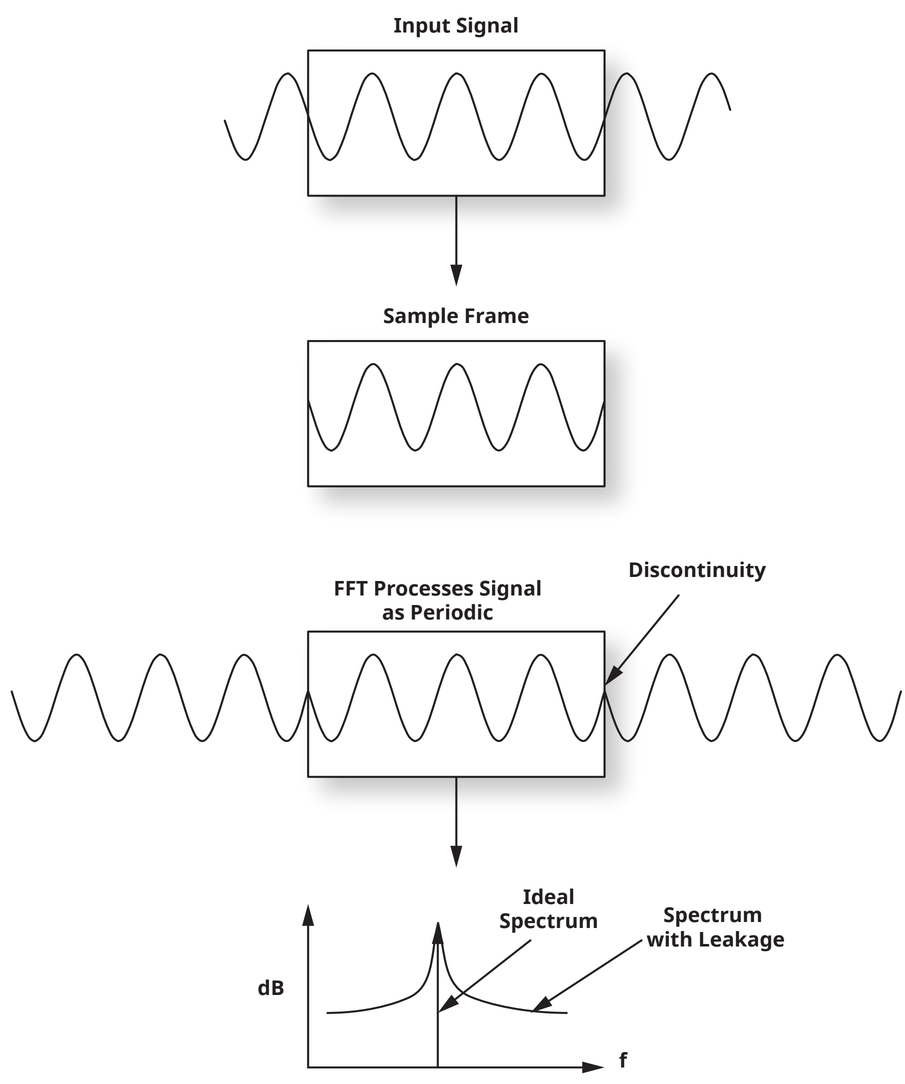

Figure 5. Applying the FFT to a sample frame without windowing can cause spectrum leakage.

Figure 5 shows a simple sine wave that is sampled over a time interval. When the sample frame is analyzed by the FFT, the samples at the start and end of the sample frame create an unwanted discontinuity when the sampled signal is treated as a periodic signal. This discontinuity in the time domain causes the frequency domain energy to be spread out instead of concentrated at the frequency of the original sine wave. Spectral leakage is also undesirable in FFT spectrum analysis since the ability to resolve closely spaced frequency components with different amplitude levels is lost. Furthermore, the amplitude of the signal is no longer an accurate representation of the true signal level because the spectrum energy has spread out.

To eliminate these effects, the samples in the sample frame are multiplied by a window function that smoothly tapers the samples near the start and end of the frame to zero. Thus when these modified samples are presented for FFT analysis, the periodic extension of this sample frame does not have a sharp discontinuity and the spectrum leakage is reduced (Figure 6).

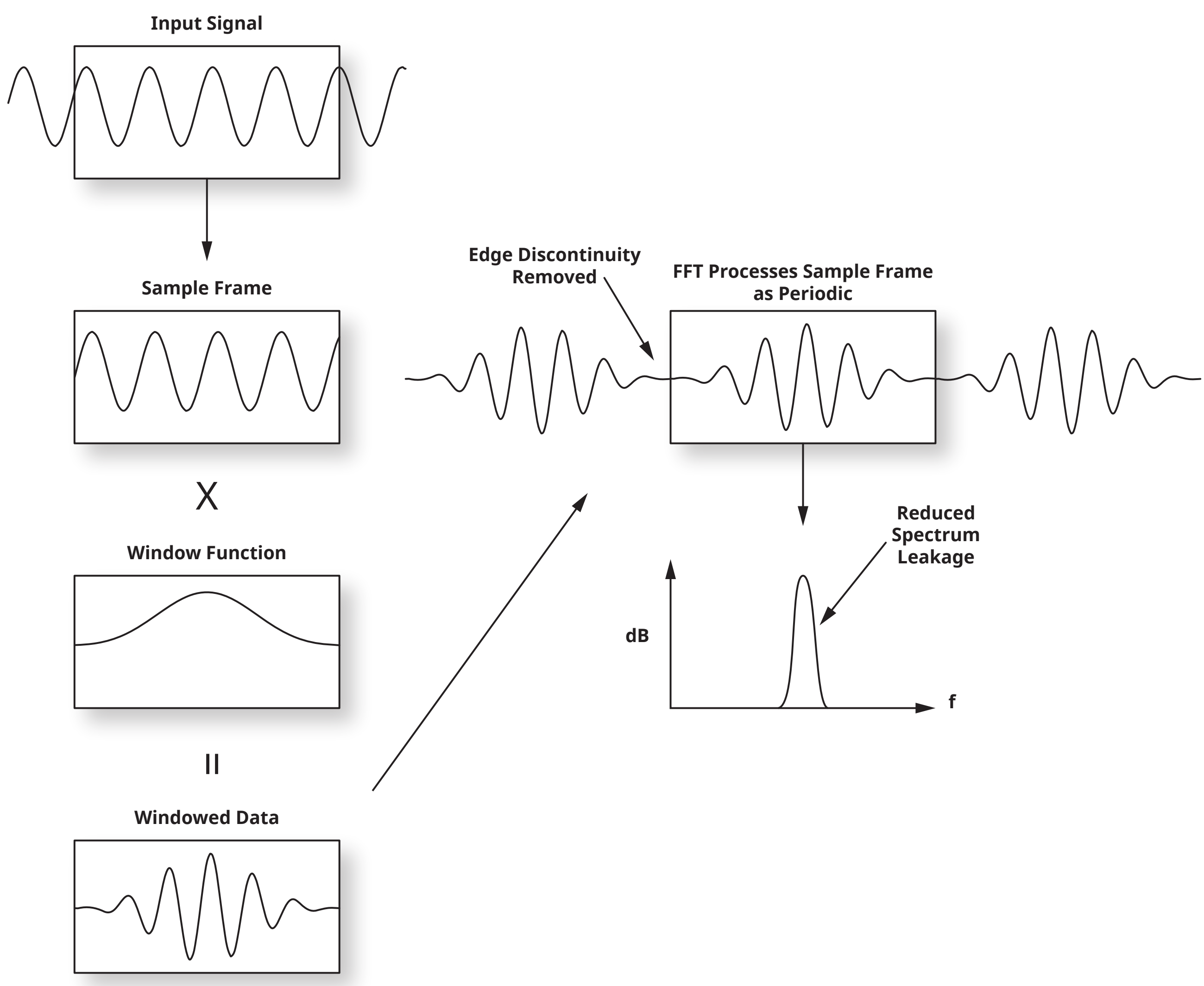

Figure 6. Windowing the input signal data before applying the FFT reduces spectrum leakage.

RBW and Span Interdependence

Windowing also serves to implement the RBW filter in FFT spectrum analysis. Performing FFT analysis on the windowed samples causes a bandpass filter response to appear around any frequency components captured within the FFT analysis bandwidth. Figure 7 shows the FFT spectrum for an input consisting of multiple CW signals that are spaced apart in frequency by one RBW. With just one capture, the FFT effectively applies a bank of parallel RBW filters to the input signal. Notice that the RBW filter response is incomplete at frequencies near the start and stop of the FFT span. Because of this, the usable bandwidth is only about 80% of the full analysis bandwidth of the FFT, which is equal to the FFT input I/Q sample rate (Fs).

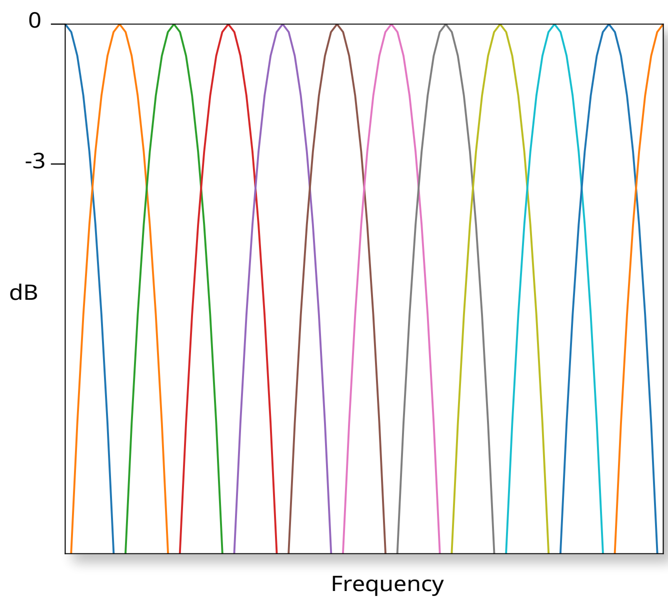

Figure 7. FFT analysis with windowing effectively forms a bank of parallel RBW filters. The figure shows the frequency spectrum for multiple CW signal inputs with a frequency spacing equal to one RBW.

There are many different types of window functions that vary in their frequency domain characteristics such as main lobe width, side lobe roll-off, and passband flatness.

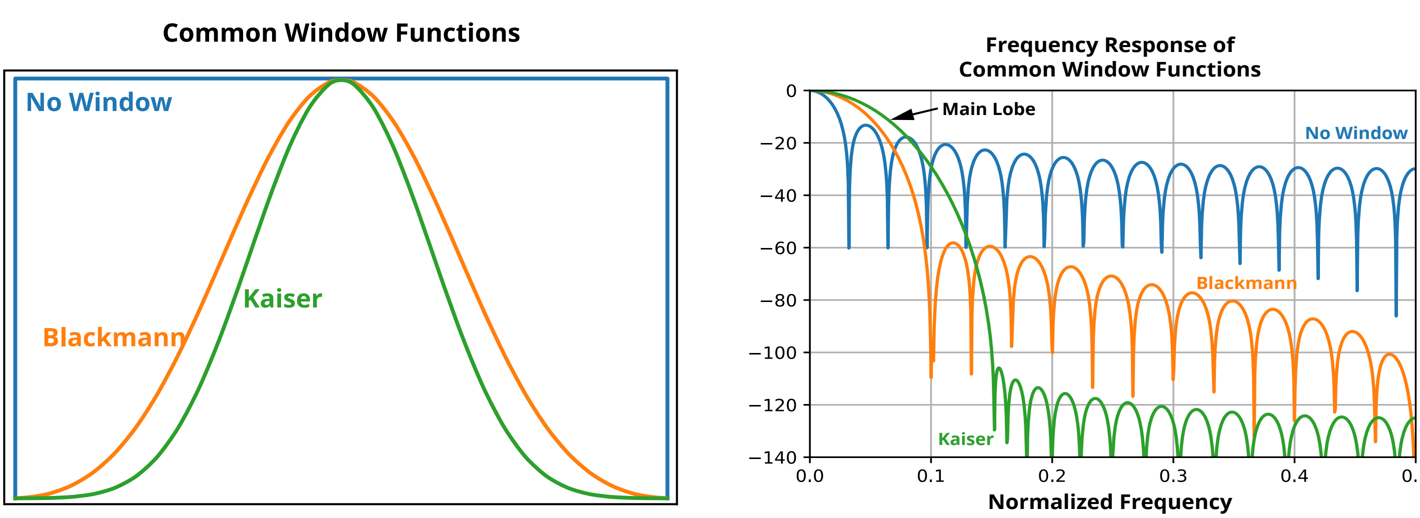

Figure 8. Time domain and frequency domain responses of common window functions.

Notice that each window function has a different main lobe width (Figure 8). The RBW filter bandwidth is equal to the 3 dB bandwidth of the window's main lobe and it is controlled by adjusting the window length (W) and FFT input I/Q sample rate (Fs). The window length can be equal to or less than the FFT size (N). The Field Master Pro MS2090A spectrum analyzer uses a Kaiser-Bessel window function with the RBW set by this formula:

$$RBW = 2.3 \times Fs/W \quad \text{and } W \leq N$$

Since the span of one FFT is also set by the sample rate, the RBW and span are interdependent. This interdependence is noticeable in a RTSA spectrum analyzer since the measurement is restricted to the span of one FFT. For example, to set a narrow RBW, the window length can increase until it reaches the maximum FFT size limit N and then the sample rate Fs must be reduced, which then forces the span to be reduced. Non-RTSA spectrum analyzers can stitch together multiple FFTs to cover a wider span, but that requires tuning the LO, during which time the analyzer is blind to signal events.

Window Overlap

Since windowing tapers the time samples at the beginning and end of the sample frame to zero, transient signal events at the edges are lost (Figure 9). Overlapping is used to ensure the capture of these signal events (Figure 10). Each sample frame for the FFT is partially filled with samples that were captured in the previous sample frame.

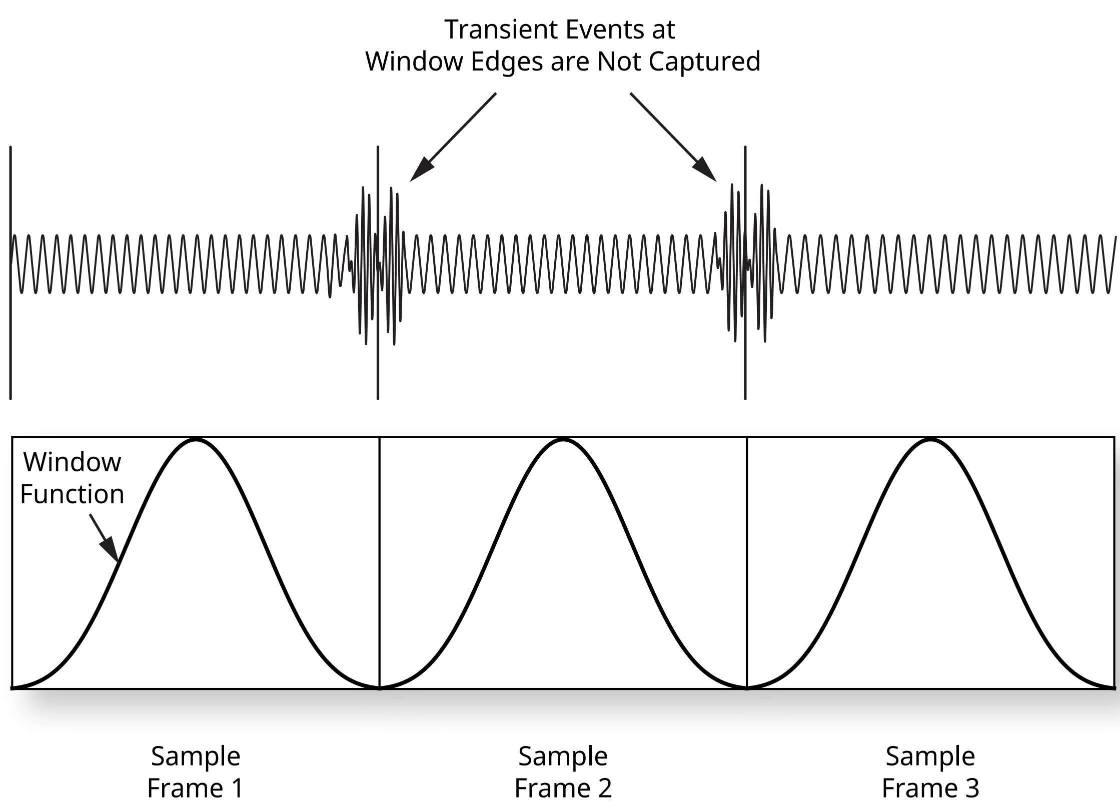

Figure 9. Transient signals occurring at the edges of a windowed sample frame will be lost.

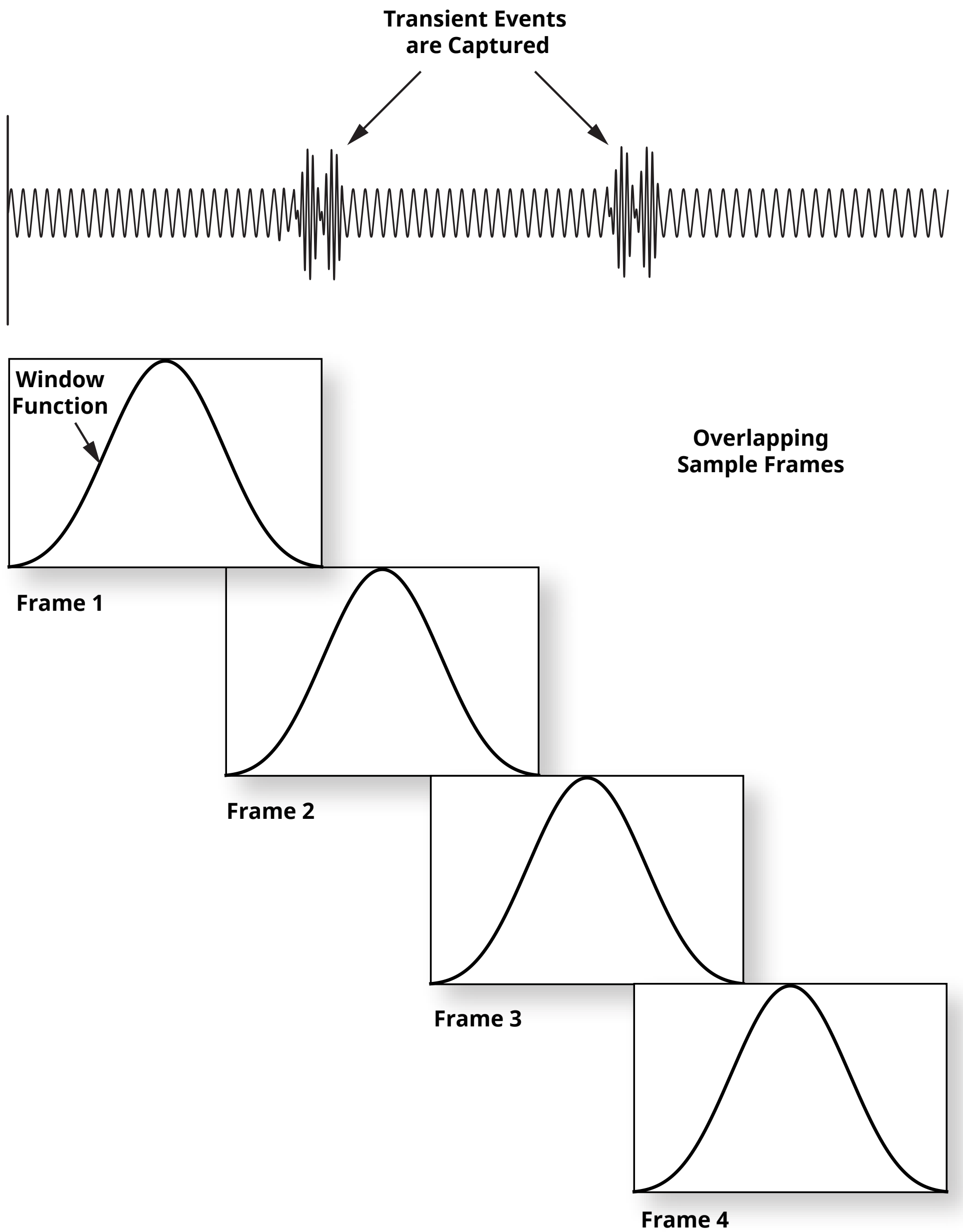

Figure 10. Overlapping samples allow the capture of events at the edges of any sample frame.

The amount of overlap in RTSA is limited by the speed of the FFT calculation relative to the input sample rate (Fs) to the FFT.

Maximum allowable overlap percentage = (FFT Clock – Fs) / FFT Clock

The FFT clock rate is the rate at which the FFT can process one sample. In the Field Master Pro MS2090A spectrum analyzer, for example, the FFT clock is 270 MHz so it can complete a 512 point FFT in 512 x 1/270 MHz = 1.9 μs or 527K FFTs per sec. The faster the FFT clock, the higher the allowable overlap. A later section will show how a higher overlap results in a shorter signal POI duration.

POI Requirement for Amplitude Accuracy

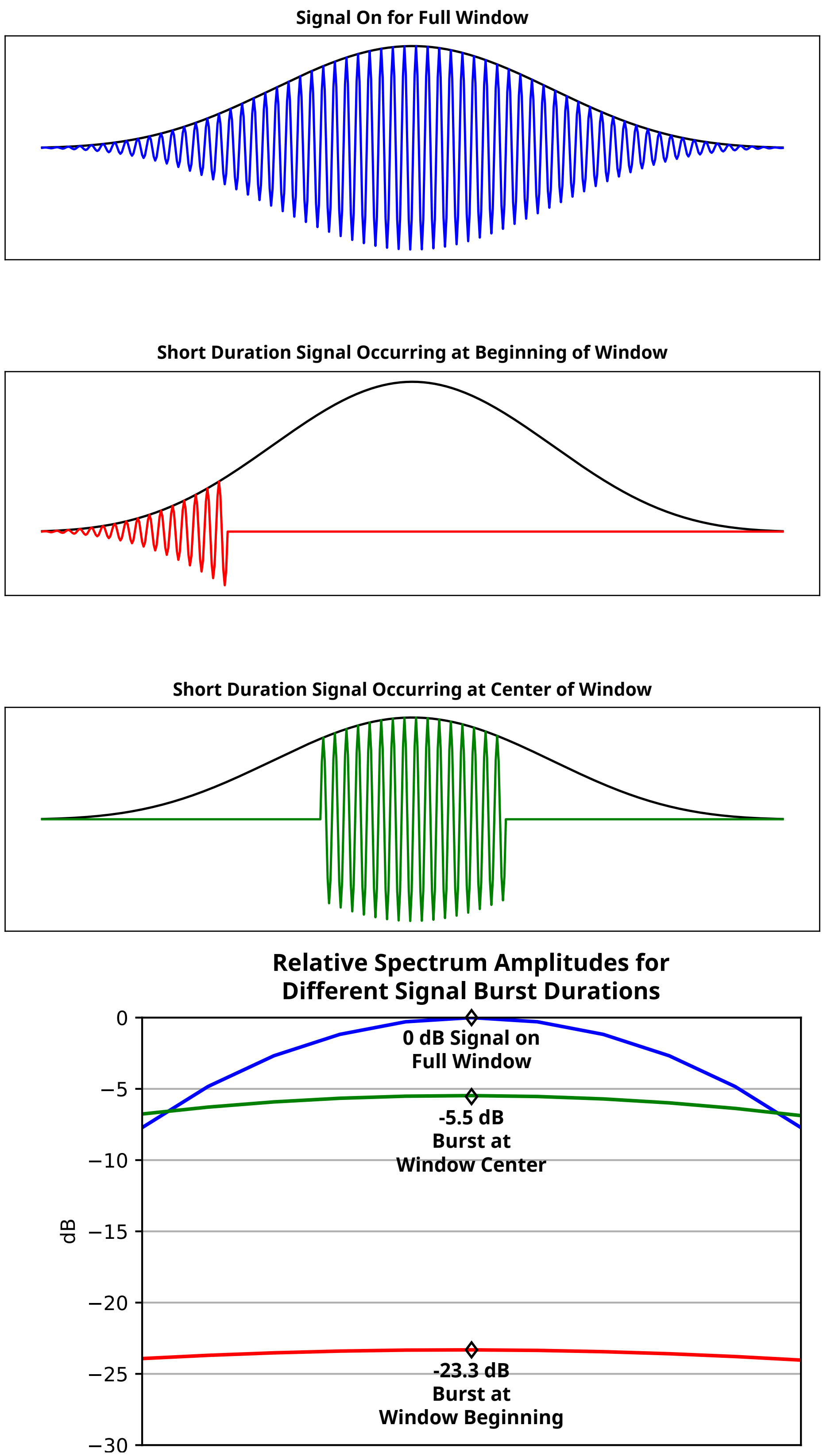

Figure 11. Signal bursts with different durations and start times have different spectrum amplitudes.

In FFT analysis, the spectrum magnitude of the signal is affected by its duration and the moment where the signal is present relative to the start of the sample frame and window function. The amplitude is proportional to the area occupied under the window function. For the same signal duration, the amplitude can differ greatly depending on when the signal burst occurred (Figure 11). The theoretical minimum detectable signal is equal to 5 ns, which is set by the maximum sample rate into the FFT of 200 MSPS (I/Q). For full amplitude accuracy, the signal has to occupy the entire area under the window function. To guarantee this condition, the signal must stay on for the duration of two consecutive sample frames in the simplest case when there is no overlapping and the window length is equal to the FFT size (sample frame size). Meeting this condition will ensure that at least one sample frame and its FFT will capture the full amplitude of the signal since the start of the signal event can occur at any time relative to the start of any sample frame (Figure 12).

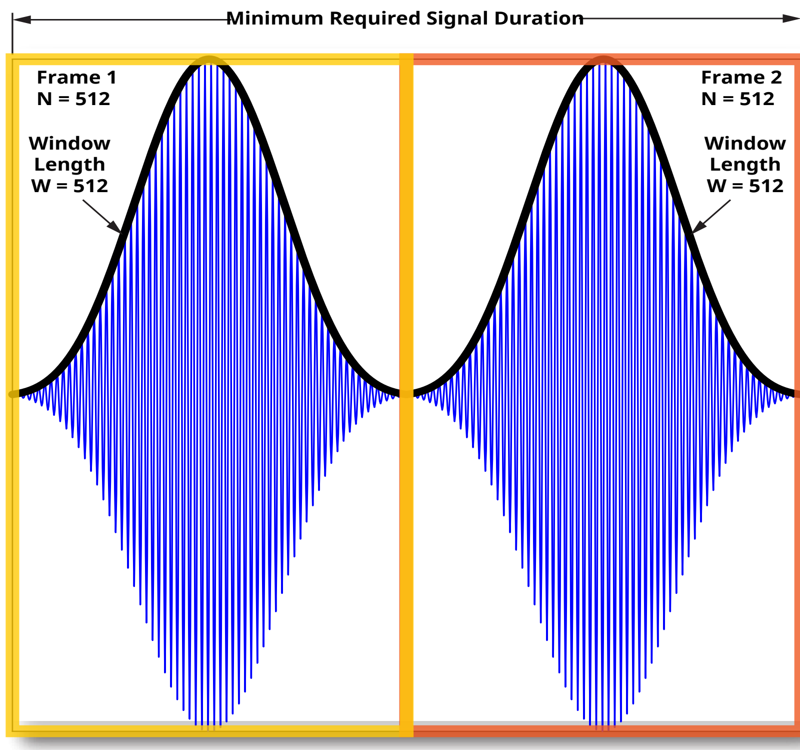

Figure 12. For 100% POI and full amplitude accuracy, the signal must be present for at least the length of two consecutive sample frames when there is no overlapping and the window length (W) is equal to the FFT size (N).

If FFT analysis is performed using overlapping sample frames, the required signal duration for 100% POI is shorter (Figure 13).

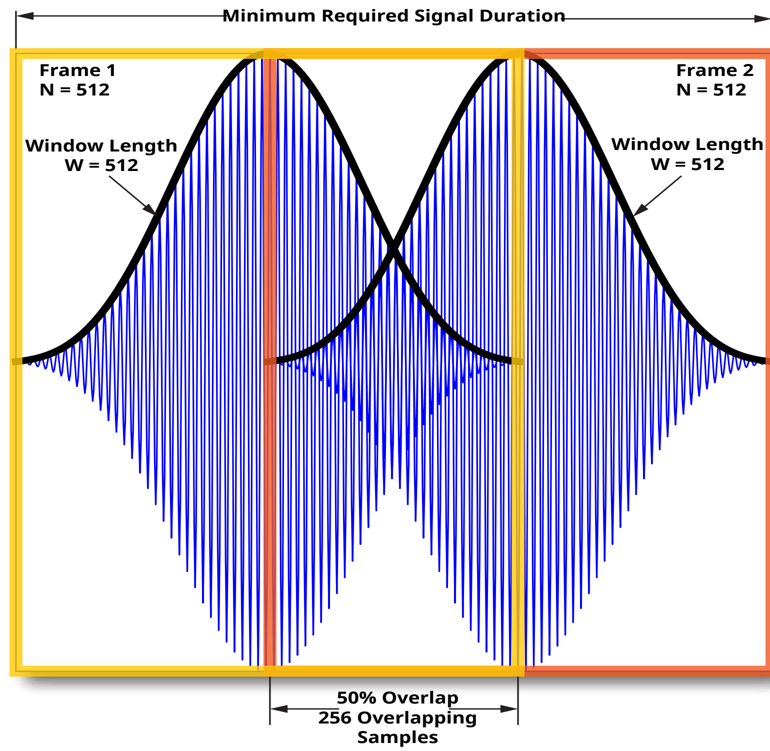

Figure 13. Overlapping reduces the minimum required signal duration for 100% POI and full amplitude accuracy. The signal must be present for at least the length of two consecutive sample frames minus the number of overlapping samples.

If the window length is smaller than the FFT size (Figure 14), the required signal duration will be shorter, thereby improving POI. Since the window length is adjusted to change RBW, the RBW setting affects POI. A wider RBW corresponds to shorter window length and shorter POI.

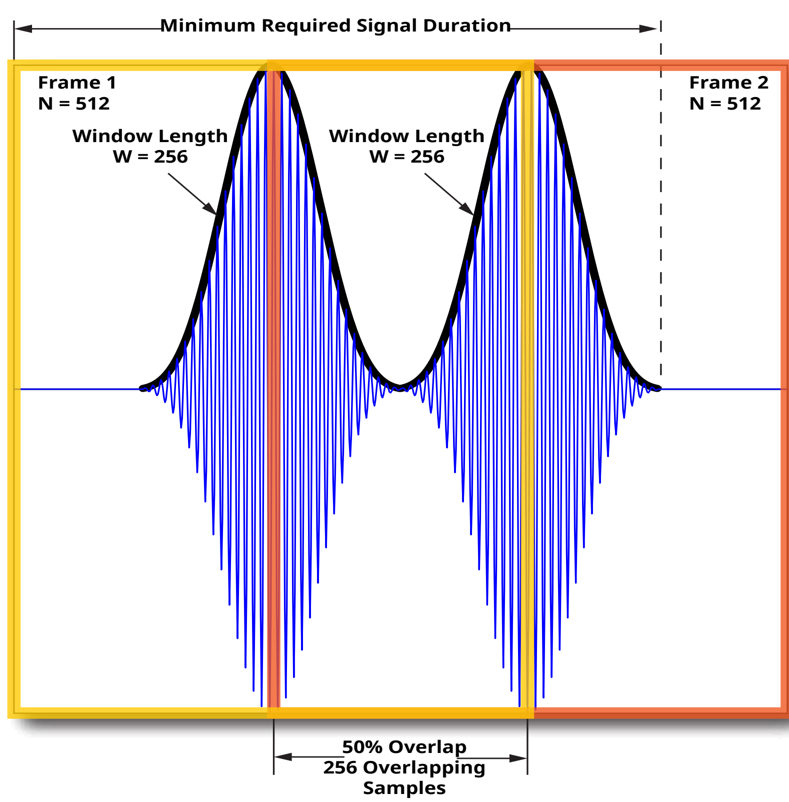

Figure 14. Using a window length (W = 256) shorter than the FFT Size, N=512, the required signal duration for 100% POI is reduced.

Based on the observations above, the required minimum signal duration for 100% POI with full amplitude accuracy is:

POI = (1/Fs) x (N + W -1 - P)
Fs = FFT input sample rate
N = FFT size, 512 or 1024 points
W = Window length
P = Number of overlapped samples = N x (FFT clock – Fs) / FFT clock
FFT Clock = 270 MHz

RBW and span are controlled by sample rate, FFT size, and window length. Since these same parameters affect POI, POI is dependent on the RBW and span settings. The Field Master Pro MS2090A spectrum analyzer automatically calculates and displays the POI for a given setup. Using the formulas above, a table for a set of POI values, RBW and SPAN can be calculated.

FFT Size = 512 (standard resolution)

				Window Length, W							
				256		128		64		32	
FFT Input Rate (I/Q) MSPS	Max Usable Span MHz	Overlap Points, P	Overlap%	POI µs	RBW MHz	POI µs	RBW MHz	POI µs	RBW MHz	POI µs	RBW MHz
200	110	132	26%	3.18	1.80	2.54	3.59	2.22	7.19	2.06	14.38
100	80	322	63%	4.45	0.90	3.17	1.80	2.53	3.59	2.21	7.19
50	40	417	81%	7.00	0.45	4.44	0.90	3.16	1.80	2.52	3.59
25	20	464	91%	12.12	0.22	7.00	0.45	4.44	0.90	3.16	1.80
12.5	10	488	95%	22.32	0.11	12.08	0.22	6.96	0.45	4.40	0.90
6.25	5	500	98%	42.72	0.06	22.24	0.11	12.00	0.22	6.88	0.45

FFT Size = 1024 (high resolution)

				Window Length, W									
				512		256		128		64		32	
FFT Input Rate (I/Q) MSPS	Max Usable Span MHz	Overlap Points, P	Overlap%	POI µs	RBW MHz	POI µs	RBW MHz	POI µs	RBW MHz	POI µs	RBW MHz	POI µs	RBW MHz
200	110	265	26%	6.35	0.90	5.07	1.80	4.43	3.59	4.11	7.19	3.95	14.38
100	80	644	63%	8.91	0.45	6.35	0.90	5.07	1.80	4.43	3.59	4.11	7.19
50	40	834	81%	14.02	0.22	8.90	0.45	6.34	0.90	5.06	1.80	4.42	3.59
25	20	929	91%	24.24	0.11	14.00	0.22	8.88	0.45	6.32	0.90	5.04	1.80
12.5	10	976	95%	44.72	0.06	24.24	0.11	14.00	0.22	8.88	0.45	6.32	0.90
6.25	5	1000	98%	85.60	0.03	44.64	0.06	24.16	0.11	13.92	0.22	8.80	0.45

Density Display Resolution

The user can select between two different FFT sizes via the density display resolution menu. The standard 512 point FFT size (Figure 15) allows for the lowest POI, however the FFT frequency bin resolution is coarser and can cause the display to appear more granular at low RBW settings. The 1024 point FFT size allows a smaller RBW setting for a given span with less display granularity at the cost of a higher POI.

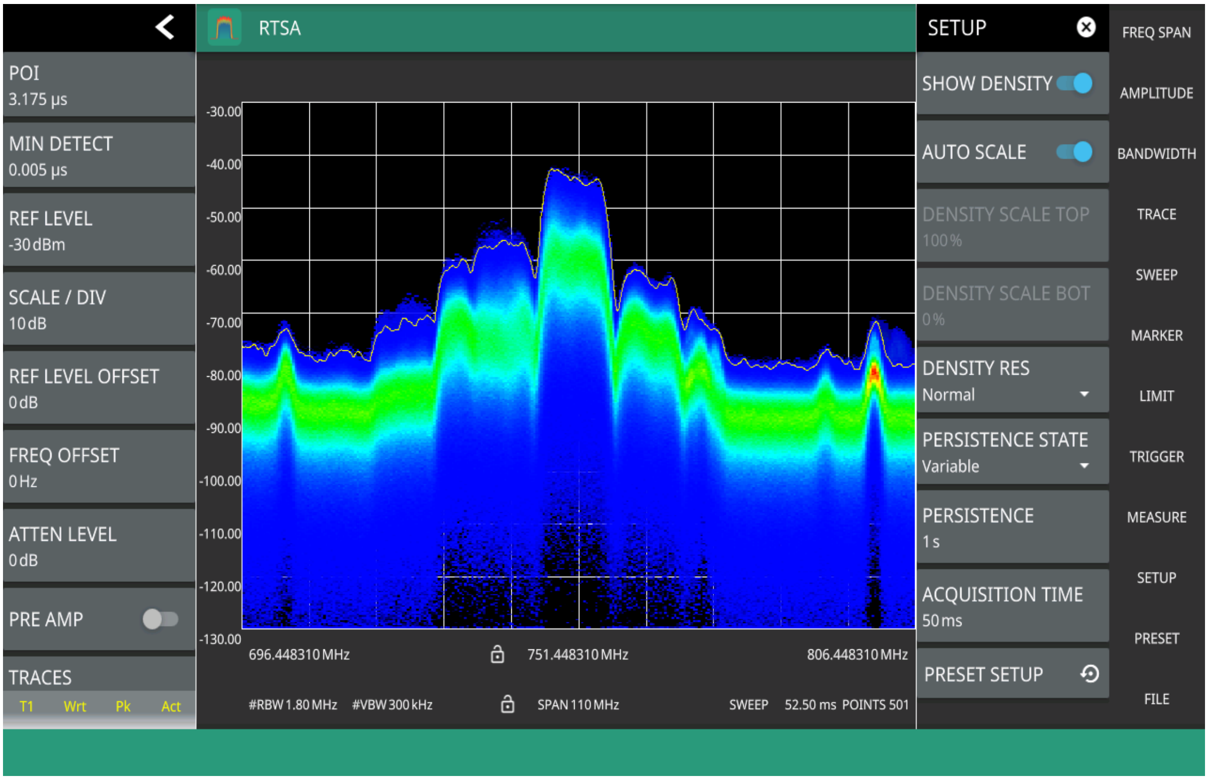

Figure 15. Density display resolution set to normal. FFT = 512 points. Minimum RBW limited to 1.8 MHz.

Density Display

The Field Master Pro MS2090A spectrum analyzer is capable of completing a 512 point FFT 527,000 times per second. This is much greater than the LCD display update rate and a density display is used to show the measurement results in a meaningful way. The density display shows the color graded intensity of a signal event. The warmer the color, the more frequent is the signal event.

During the acquisition time interval, a number of FFTs are calculated and their measurement results are mapped to a hit map frame. It counts the occurrence of a FFT measurement result that falls into a particular frequency and amplitude bin. The display amplitude range is divided into 320 bins, and the number of frequency bins depends on the FFT size and span settings. In effect, the hit map is a 2 dimensional histogram for frequency and amplitude.

With autoscale on, the counts are normalized to the highest count value in the entire hit map and a color scale is assigned to the normalized count values. If autoscale is off, then the count values are normalized to the number of FFT measurements taken during the acquisition time. The assignment of color values to the normalized count values converts the hit map into a pixel map for the display. For bins with no hits (count value = 0), no color is assigned and the bin is mapped as transparent (Figure 16).

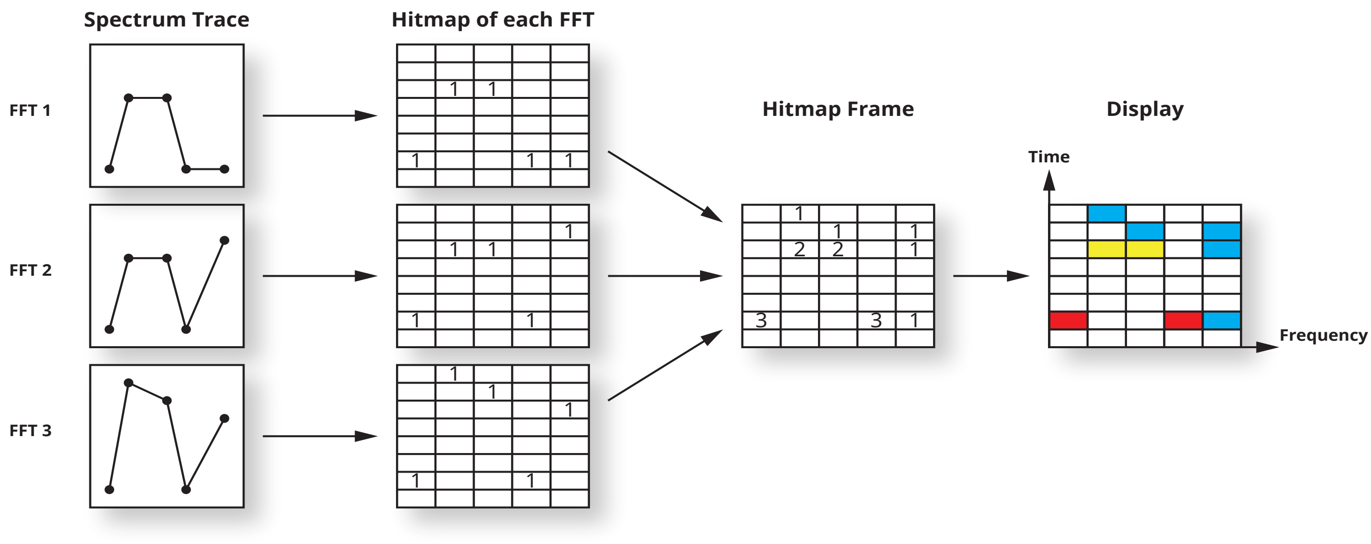

Figure 16. Shows the density display processing steps for three FFTs acquired during the acquisisiton time interval.

The density display also can simultaneously show up to 6 spectrum traces. The spectrum traces represent the detection result for all the FFTs calculated during the acquisition interval. Peak and negative peak detection selects, respectively, the maximum or minimum amplitude level detected for each frequency point. In sample detection, the trace values represent the amplitudes from one single FFT acquired during the acquisition interval (Figure 17).

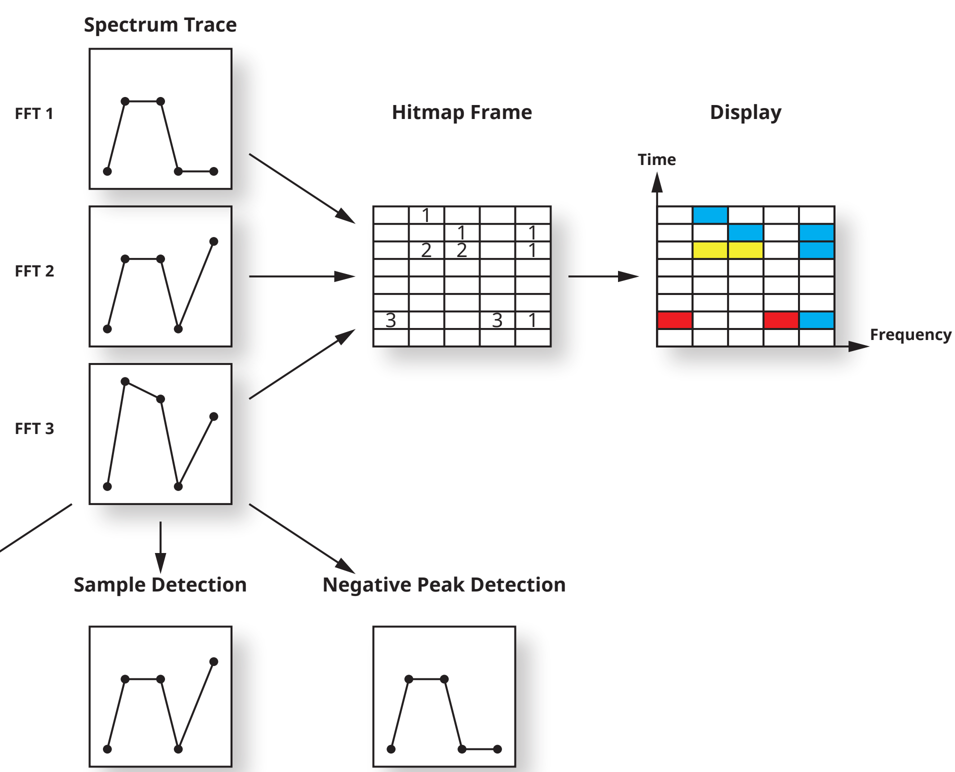

Figure 17. Shows how the spectrum traces are constructed from the detected amplitude of all three FFTs acquired during the acquisition time interval.

Persistence State

The persistence state controls how old, transient events are presented on the density display. The density display shows a new hit map frame for each acquisition period. Each hit map frame overwrites the previous hit map frame unless a bin is transparent (no hit count). For transparent bins, the color of the corresponding bin on the previous hit map frame is retained, but it begins to fade to transparent at a rate proportional to the acquisition time/persistence time when the persistence state is set to variable. For infinite persistence, there is no fading. Old hits remain on the display until they are overwritten by new hits from a later signal event at the same frequency and amplitude bin (Figure 18).

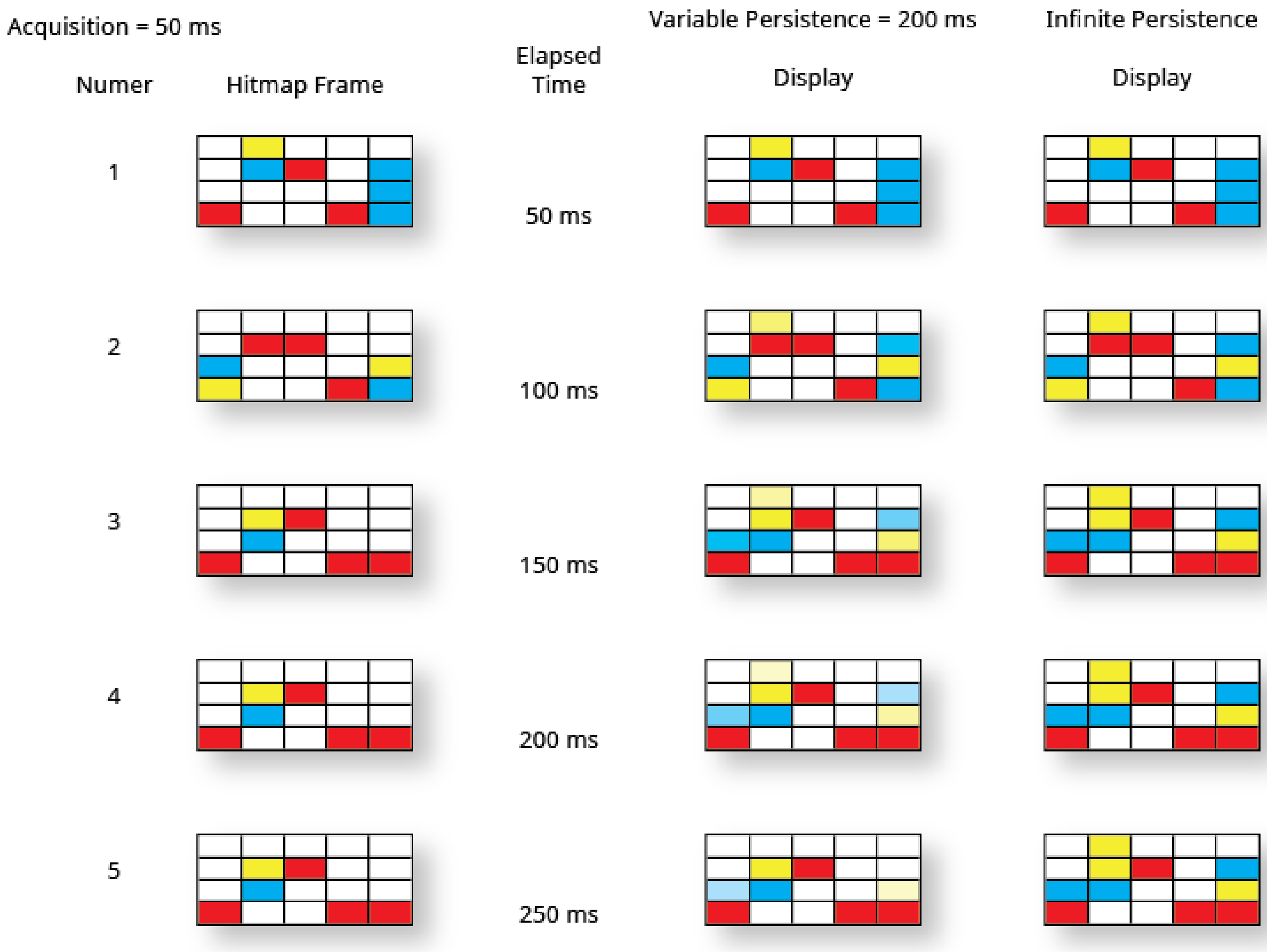

Figure 18. Shows how the dosplay pixels change after each acquisition for the variable and infinite presistence states.

Spectrogram

A spectrogram displays spectrum vs. time. Each line of the spectrogram is created from a normal spectrum trace with its amplitude values mapped to a user-adjustable color scale (Figure 19). Each line represents the detected amplitude of many FFTs during the user settable acquisition time (50ms – 5s). The user can select three different detection methods: max, negative peak, sample. After every acquisition interval, a new line is added to the bottom of the spectrogram and the oldest spectrogram line is discarded from the top. The spectrogram has 142 lines and the maximum displayed time record is 142 x acquisition time. Internally, there is a spectrogram buffer that stores more than 142 lines and the data can be accessed via a SCPI command.

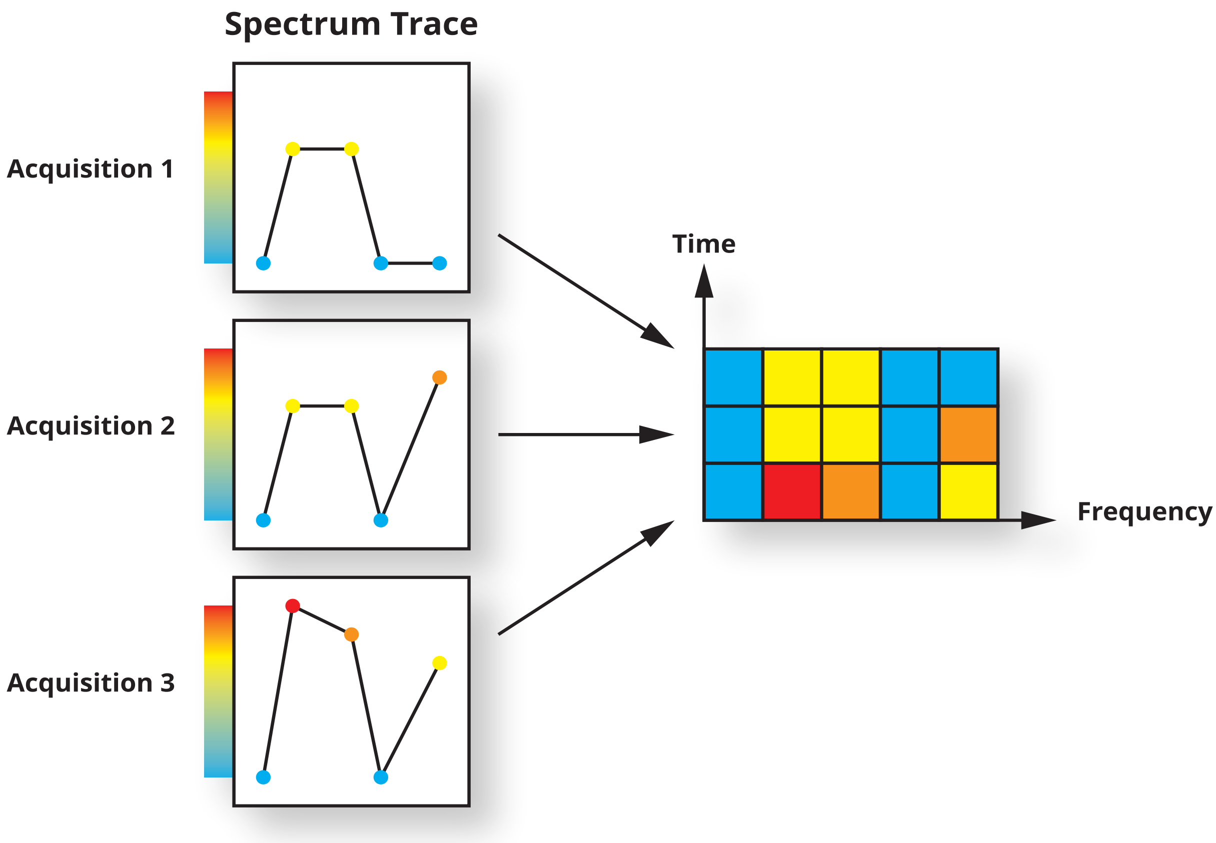

Figure 19. The spectrogram is built up one line at a time. Each line is a trace result acquired over one acquisition interval.

The spectrogram differs from the density display in that it does not provide an indication of the number of occurrences of a signal event during the acquisition time. It simply shows the maximum, minimum, or a sample value of the amplitude detected during the acquisition time at a particular signal frequency. Figure 20 provides an example of both a spectrogram and density display.

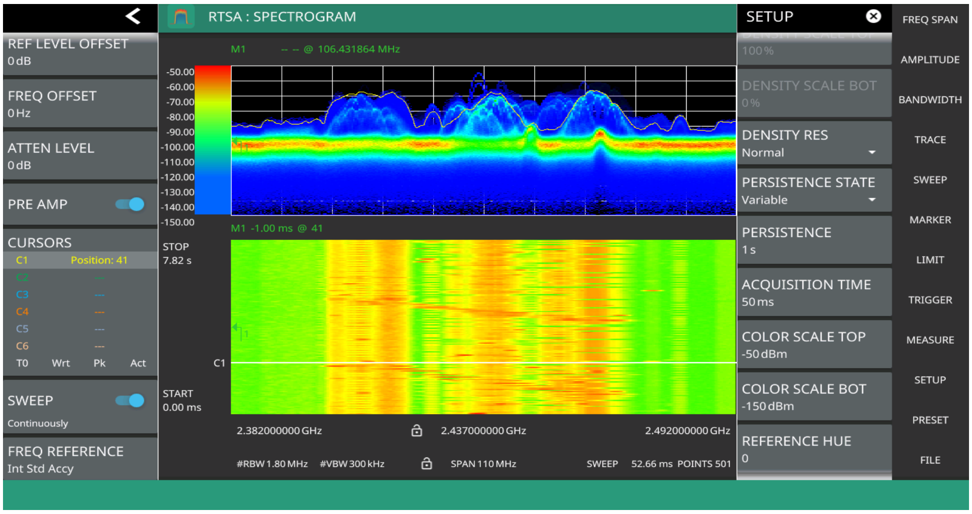

Figure 20. Density display and spectrogram showing activity in the 2.4 GHz ISM band.

Field Master Pro MS2090A Spectrum Analyzer Summary of Key Parameters

FFT Size, N = 512 or 1024 points

FFT speed = 263K/sec for 1024 point FFT, 527K/sec for 512 point FFT Window Length, W = 32 to N/2

Window Type: Kaiser-Bessel

RBW = Window main lobe 3 dB bandwidth = 2.3 x Fs / W

Max FFT input (I/Q) data rate, Fs = 200 MSPS

Min POI = 2.06 μs

Min Detectable Signal = 5 ns

FFT Usable bandwidth (Span) in RTSA mode = 0.8 x Fs, with maximum of 110 MHz

FFT Frequency Resolution = Fs / N

CONCLUSION

Advances in technology and design have enabled the creation of the first high performance real-time handheld spectrum analyzer with a 110 MHz analysis bandwidth and a 100% probability of intercept duration of 2.06 μs. Together with the variable persistence density display and spectrogram, the Anritsu Field Master Pro MS2090A spectrum analyzer is well suited to meet challenges in analyzing dynamic RF signal events and detecting transient interferers, and unwanted, hidden signals.

Specifications are subject to change without notice.

• **United States**
Anritsu Americas Sales Company
450 Century Parkway, Suite 190, Allen,
TX 75013 U.S.A.
Phone: +1-800-Anritsu (1-800-267-4878)

• **Canada**
Anritsu Electronics Ltd.
700 Silver Seven Road, Suite 120, Kanata,
Ontario K2V 1C3, Canada
Phone: +1-613-591-2003
Fax: +1-613-591-1006

• **Brazil**
Anritsu Eletronica Ltda.
Praça Amadeu Amaral, 27 - 1 Andar
01327-010 - Bela Vista - Sao Paulo - SP
Brazil
Phone: +55-11-3283-2511
Fax: +55-11-3288-6940

• **Mexico**
Anritsu Company, S.A. de C.V.
Blvd Miguel de Cervantes Saavedra #169 Piso 1, Col. Granada
Mexico, Ciudad de Mexico, 11520, MEXICO
Phone: +52-55-4169-7104

• **United Kingdom**
Anritsu EMEA Ltd.
200 Capability Green, Luton, Bedfordshire, LU1 3LU, U.K.
Phone: +44-1582-433200
Fax: +44-1582-731303

• **France**
Anritsu S.A.
12 avenue du Québec, Bâtiment Iris 1- Silic 612,
91140 VILLEBON SUR YVETTE, France
Phone: +33-1-60-92-15-50
Fax: +33-1-64-46-10-65

• **Germany**
Anritsu GmbH
Nemetschek Haus, Konrad-Zuse-Platz 1
81829 München, Germany
Phone: +49-89-442308-0
Fax: +49-89-442308-55

• **Italy**
Anritsu S.r.l.
Via Elio Vittorini 129, 00144 Roma, Italy
Phone: +39-6-509-9711
Fax: +39-6-502-2425

• **Sweden**
Anritsu AB
Isafjordsgatan 32C, 164 40 KISTA, Sweden
Phone: +46-8-534-707-00

• **Finland**
Anritsu AB
Teknobulevardi 3-5, FI-01530 VANTAA, Finland
Phone: +358-20-741-8100
Fax: +358-20-741-8111

• **Denmark**
Anritsu A/S
Torveporten 2, 2500 Valby, Denmark
Phone: +45-7211-2200
Fax: +45-7211-2210

• **Russia**
Anritsu EMEA Ltd.
Representation Office in Russia
Tverskaya str. 16/2, bld. 1, 7th floor.
Moscow, 125009, Russia
Phone: +7-495-363-1694
Fax: +7-495-935-8962

• **Spain**
Anritsu EMEA Ltd.
Representation Office in Spain
Edificio Cuzco IV, Po. de la Castellana, 141, Pta. 5
28046, Madrid, Spain
Phone: +34-915-726-761
Fax: +34-915-726-621

• **United Arab Emirates**
Anritsu EMEA Ltd.
Dubai Liaison Office
902, Aurora Tower,
P O Box: 500311- Dubai Internet City
Dubai, United Arab Emirates
Phone: +971-4-3758479
Fax: +971-4-4249036

• **India**
Anritsu India Private Limited
6th Floor, Indiqube ETA, No.38/4, Adjacent to EMC2,
Doddanekundi, Outer Ring Road, Bengaluru – 560048, India
Phone: +91-80-6728-1300
Fax: +91-80-6728-1301

• **Singapore**
Anritsu Pte. Ltd.
11 Chang Charn Road, #04-01, Shriro House
Singapore 159640
Phone: +65-6282-2400
Fax: +65-6282-2533

• **P.R. China (Shanghai)**
Anritsu (China) Co., Ltd.
Room 2701-2705, Tower A,
New Caohejing International Business Center
No. 391 Gui Ping Road Shanghai, 200233, P.R. China
Phone: +86-21-6237-0898
Fax: +86-21-6237-0899

• **P.R. China (Hong Kong)**
Anritsu Company Ltd.
Unit 1006-7, 10/F., Greenfield Tower, Concordia Plaza,
No. 1 Science Museum Road, Tsim Sha Tsui East,
Kowloon, Hong Kong, P.R. China
Phone: +852-2301-4980
Fax: +852-2301-3545

• **Japan**
Anritsu Corporation
8-5, Tamura-cho, Atsugi-shi, Kanagawa, 243-0016 Japan
Phone: +81-46-296-6509
Fax: +81-46-225-8352

• **Korea**
Anritsu Corporation, Ltd.
5FL, 235 Pangyoyeok-ro, Bundang-gu, Seongnam-si,
Gyeonggi-do, 13494 Korea
Phone: +82-31-696-7750
Fax: +82-31-696-7751

• **Australia**
Anritsu Pty. Ltd.
Unit 20, 21-35 Ricketts Road,
Mount Waverley, Victoria 3149, Australia
Phone: +61-3-9558-8177
Fax: +61-3-9558-8255

• **Taiwan**
Anritsu Company Inc.
7F, No. 316, Sec. 1, NeiHu Rd., Taipei 114, Taiwan
Phone: +886-2-8751-1816
Fax: +886-2-8751-1817

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