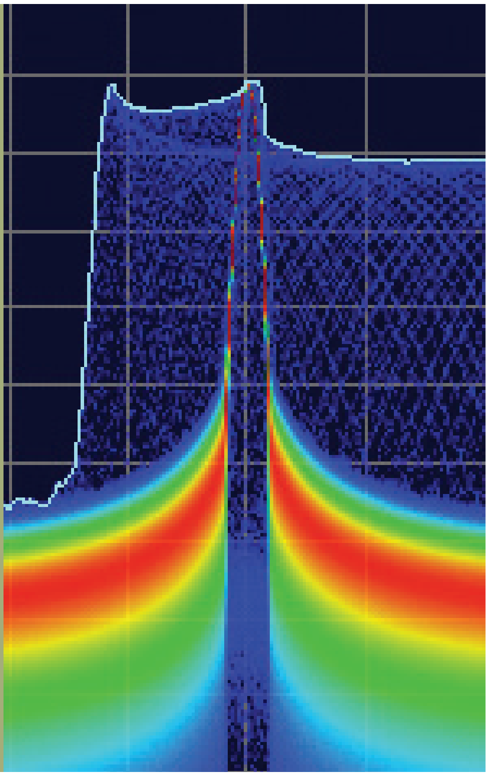

DPX® Acquisition Technology for Spectrum Analyzers Fundamentals

Primer

Tektronix®

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A Revolutionary Tool for Signal Discovery, Trigger, Capture and Analysis

Detection is the first step in characterizing, diagnosing, understanding and resolving any problem relating to time-variant signals. As more channels crowd into available bandwidth, new applications utilize wireless transmission, and RF systems become digital-based, engineers need better tools to help them find and interpret complex behaviors and interactions.

Tektronix patented Digital Phosphor technology, or DPX®, is used in our Real-Time Spectrum Analyzers (RSAs) to reveal signal details that are completely missed by conventional spectrum analyzers and vector signal analyzers. The full-motion DPX Live RF spectrum display shows signals never seen before, giving users instant insight and greatly accelerating discovery and diagnosis. DPX is standard on all Tektronix RSAs. With the recently introduced, real-time DPX Time-Domain display technology, Tektronix Real-Time Spectrum Analyzers now become Real-Time Signal Analyzers.

This primer describes the methods behind the DPX Live RF spectrum display, swept DPX, Time-Domain DPX Displays, DPX Density™ measurements, DPX Density™ and Frequency Edge triggers.

- **Swept DPX** revolutionizes spectrum analysis by enlarging the DPX span to cover the instrument's entire frequency range. The analyzer acquires a wide span as a series of real-time segments, each tens of megahertz wide, merging them into a complete DPX Spectrum graph.
- **Time-Domain DPX** transform real-time viewing from spectrum viewing to methods of analysis for detailed signal analysis. With real-time views of amplitude (Zero Span), phase, and frequency versus time at update rates that are orders of magnitude faster than conventional signal analyzers.
- **DPX Density™** trigger is a completely new way to catch the signals you discover with the DPX Spectrum display. In many cases, it is the only way to capture signals hiding beneath other signals. While just seeing these signals in the DPX display is sometimes enough to set you on the track to diagnosis, it is often important to acquire a data record of the signal for further analysis.
- **Frequency Edge** trigger provide another unique method of signal isolation that runs concurrently within the DPX engine to isolate signal transition at a specific frequency and threshold. By combining this functionality with trigger interpolation, you now have a unique, low jitter, method for analyzing signal frequency transitions.

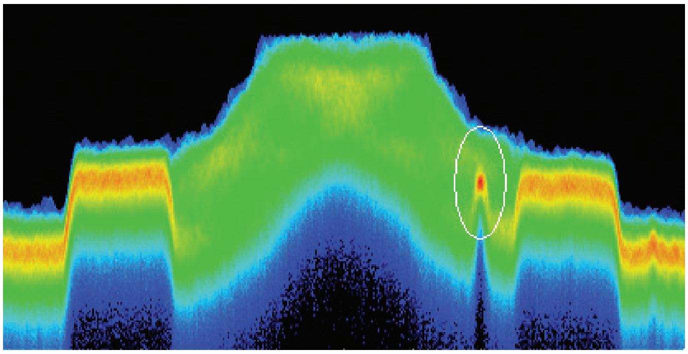


Figure 1. Circled signal shows a narrowband interference transmission buried in High Definition FM radio signal.

One example, Figure 1, demonstrates a hard-to-catch signal is an unexpected narrow-band transmission buried in the FM signal. No previous method for triggering in the time or frequency domain will enable the event triggering and isolation of this event. DPX Density trigger now enables a method for triggering on the persistency (or time density) of the signal.

Additional advancements in DPX performance and functionality include major increases in speed and z-axis resolution. Faster spectral transforms (>290,000 per second) guarantee display of events as short as 3.7 μsec, plus better visual representation of transient signals. Higher resolution in the Z axis provides accurate measurements of signal density at any frequency-amplitude point in the DPX Spectrum graph. Color scaling for the density axis has been enhanced by the addition of user-adjustable mapping.

One-click automation features will have you using these valuable new capabilities within minutes of turning on your new or upgraded instrument. The first of these is Auto Color, which quickly adjusts the color range of the DPX bitmap for whatever signals are currently displayed. The other is Trigger On This™, a pop-up menu selection that turns on DPX Density triggering and sets its parameters to capture the signal you clicked on.

DPX capabilities and features referenced in this primer may not be available in all Tektronix spectrum analyzers. The functionality described in this document is representative of a fully equipped RSA5000 and RSA6000 Series spectrum analyzers equipped with Option 200.

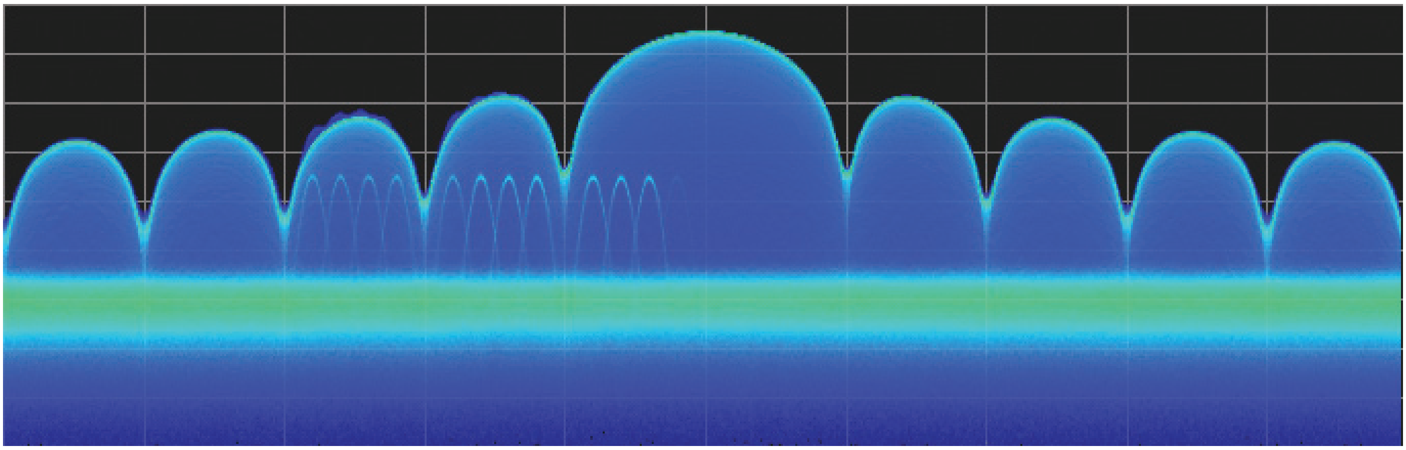


Figure 2. DPX spectrum display reveals low amplitude signals in the presence of larger signals.

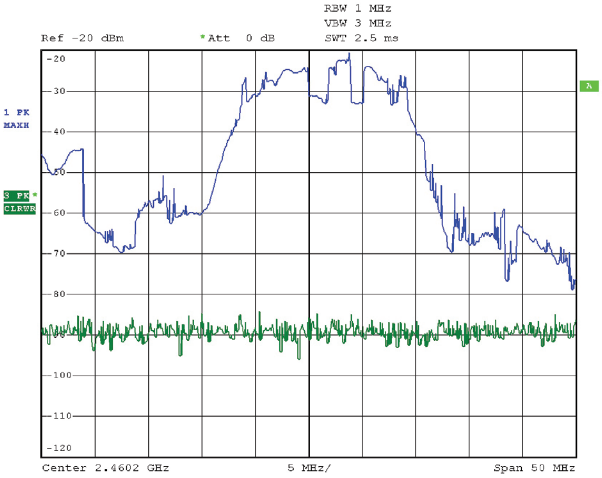


Figure 3. Max Hold and Normal traces on a swept spectrum analyzer, both using +Peak detection. The Max Hold trace shows the laptop’s stronger signal, but neither trace shows the lower-level of the access point transmissions.

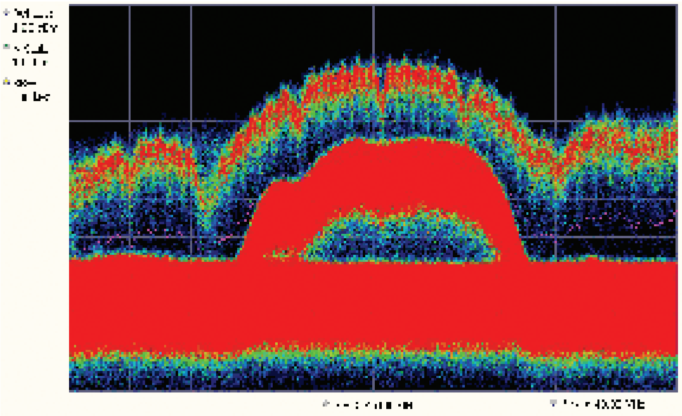


Figure 4. The RSA6000 Series shows the laptop transmissions, access point signal and background noise, all in its live-motion bitmap trace.

The DPX Display

With the DPX Spectrum display you can detect and accurately measure transients as brief as 3.7 µsec. Dedicated hardware computes up to 292,000 spectrums per second on the digitized input signal. Then it displays all these spectrums as a color-graded bitmap that reveals low-amplitude signals beneath stronger signals sharing the same frequency at different times.

The strong signal in the DPX spectrum graph, shown in Figure 2, is a repeating pulse at a fixed frequency. There is also a lower-power CW signal that steps very quickly through the same span. During the pulse's on time, the power of the two signals is additive, resulting in nearly undetectable differences in the pulse envelope shape. But during the time the pulse is off, the sweeping signal is detected and shown in its true form. Both signals are visible in the bitmap because at least one full cycle of their activities occurs within a single DPX display update.

Compare the display of a traditional swept spectrum analyzer (Figure 3) and that of a real-time spectrum analyzer with a DPX spectrum display (Figure 4). The signal captured is a typical WLAN interchange between a nearby PC and a more-distant network access point (AP). The laptop signal is nearly 30 dB stronger than the AP's signal because it is closer to the measuring antenna.

The traditional swept spectrum analyzer display, Figure 3, uses line traces that can show only one level for each frequency point, representing the largest, the smallest or the average power. After many sweeps, the Max Hold trace shows a rough envelope of the stronger laptop signal. +Peak detection was selected for the other trace in an attempt to capture the weaker but more frequent AP signal, but the bursts are very brief, so the likelihood of seeing one in any particular sweep is small. It will also take a long time to statistically capture the entire spectrum of a bursted signal due to the architecture of the swept spectrum analysis.

Simplified Flow of Multi-stage Processing from RF Input Through to Spectrum Processing:

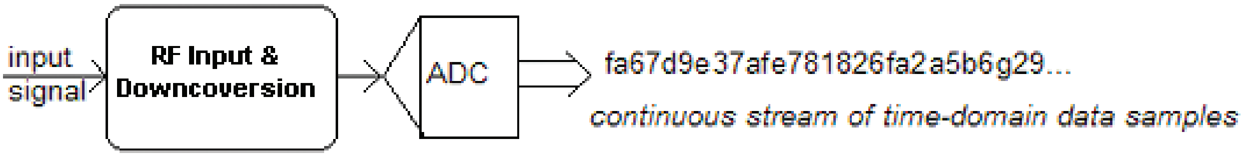


Figure 5a. RF signals are downconverted and sampled into a continuous data stream.

Figure 5b. Samples are segmented into data records for FFT processing based on the selected resolution bandwidth.

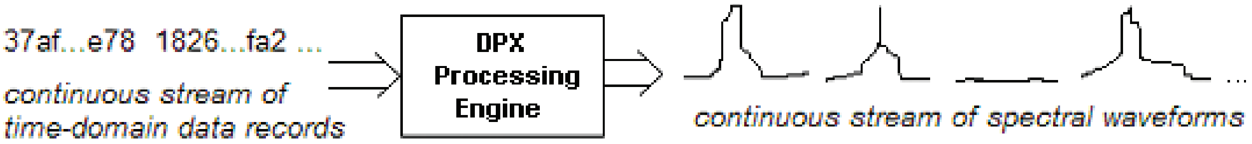


Figure 5c. Data records are processed in DPX transform engine.

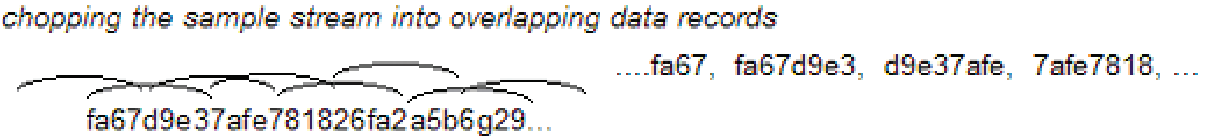


Figure 5d. For some products, overlapped FFT processing is used to improve minimum event processing.

The DPX spectrum display, Figure 4, reveals much more insight on the same signal. Since it is a bitmap image instead of a line trace, you can distinguish many different signals occurring within each update period and/or different version of the same signal varying over time. The heavy band running straight across the lower third of the graph is the noise background when neither the laptop nor the AP is transmitting. The red lump of energy in the middle is the ON shape of the AP signal. Finally, the more delicate spectrum above the others is the laptop transmissions. In the color scheme used for this demonstration (“Temperature”), the hot red color indicates a signal that is much more frequent than signals shown in cooler colors. The laptop signal, in yellow, green and blue, has higher amplitude but doesn't occur nearly as often as the AP transmissions because the laptop was downloading a file when this screen capture was taken.

Behind the Scenes: How DPX Works

This section explains how DPX spectrum displays are created. The input RF signal is conditioned and down-converted as usual for a spectrum analyzer, then digitized. The digitized data is sent through an FPGA that computes very fast spectral transforms, and the resulting frequency-domain waveforms are rasterized to create the bitmaps.

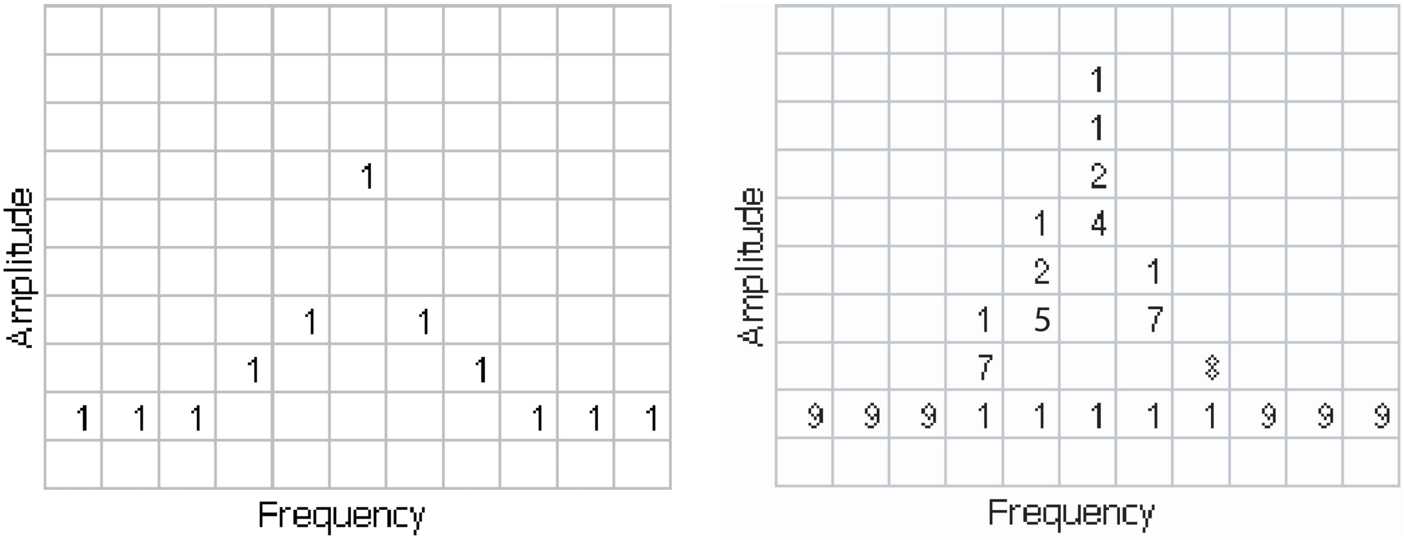
The DPX bitmap that you see on screen is composed of pixels representing x, y, and z values for frequency, amplitude, and hit count (some instruments can be upgraded to enable the z-axis measurement Density in place of hit count). A multi-stage process, shown in Figures 5a - 5d, creates this bitmap, starting with analog-to-digital conversion of the input signal.

Collecting Spectral Data

Sampling and digitization is continuous. The digitized data stream is chopped into data records whose length is based on the desired resolution bandwidth (RBW). Then the DPX transform engine performs a discrete Fourier transform on each record, continually producing spectral waveforms.

a) RF signals are downconverted and sampled into a continuous data stream.

b) Samples are segmented into data records for FFT processing based on the selected resolution bandwidth.



					1					
				1		1				
			1				1			
1	1	1						1	1	1

					1					
					1					
					2					
				1	4					
				2		1				
			1	5		7				
			7				8			
9	9	9	1	1	1	1	1	9	9	9

Figure 6. Example 3-D Bitmap Database after 1 (left) and 9 (right) updates. Note that each column contains the same total number of “hits”.

c) Data records are process in DPX transform engine.

d) For some products, over-lapped FFT processing is used to improve minimum event duration performance.

As long as spectral transforms are performed faster than the acquisition data records arrive, the transforms can overlap each other in time, so no events are missed in between. Minimum event length for guaranteed capture depends on the length of the data records being transformed. An event must last through two consecutive data records in order for its amplitude to be accurately measured. Shorter events are detected and visible on screen, but may be attenuated. The DPX Spectrum RBW setting determines the data record length; narrow RBW filters have a longer time constant than wide RBW filters. This longer time constant requires longer FFTs, reducing the transform rate. Additional detail on minimum signal duration is provided in “Guaranteed Capture of Fast Events” later in this primer.

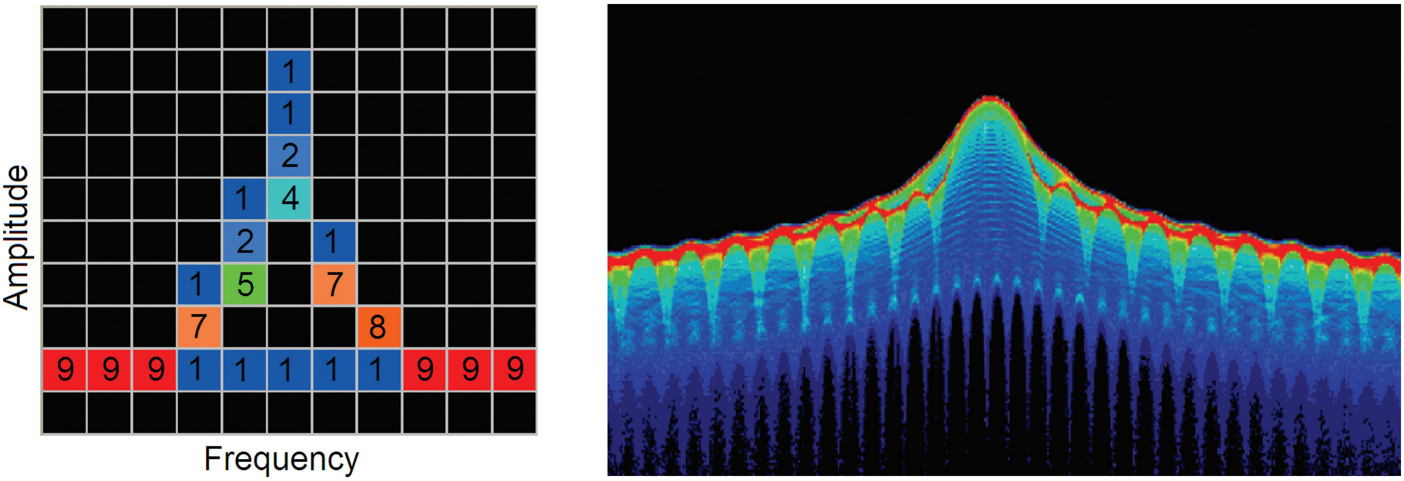
The spectral waveforms are plotted onto a grid of counting cells called the “bitmap database”. The number held by each database cell is the z-axis count. For simplicity, the small example grid used here in Figure 6 is 11x10, so our spectral waveforms will each contain 11 points. A waveform contains one (y) amplitude value for each (x) frequency. As waveforms are plotted to the grid, the cells increment their values each time they receive a waveform point.

The grid on the left shows what the database cells might contain after a single spectrum is plotted into it. Blank cells contain the value zero, meaning that no points from a spectrum have fallen into them yet.

The grid on the right shows values that our simplified database might contain after an additional eight spectral transforms have been performed and their results stored in the cells. One of the nine spectrums happened to be computed as a time during which the signal was absent, as you can see by the string of “1” occurrence counts at the noise floor.

Frame Updates

The maximum rate for performing the variable-length frequency transforms that produce those waveforms can be greater than 292,000 per second. Measurement settings that slow this transform rate include narrowing the RBW and increasing the number of points for the line traces available in the DPX Spectrum display along with the bitmap. Even at their slowest, spectral transforms are performed orders of magnitude faster than a physical display can respond, and also too fast for humans to see, so there's no need to update the screen or measurements at this rate. Instead, the grid collects thousands of waveforms into “frames”, each covering about 50 milliseconds (ms). A 50 ms frame contains the counts from up to 14,600 waveforms. After each frame's waveforms have been mapped into the grid, the cell occurrence counts are converted to colors and written to the DPX bitmap, resulting in a bitmap update rate of around 20 per second.



					1					
					1					
					2					
				1	4					
				2		1				
			1	5		7				
			7				8			
9	9	9	1	1	1	1	1	9	9	9

Figure 8. Color-coded low-resollution example (left) and a real DPX display (right).

Number of Occurrences	Color
0	black
1	blue
2	light blue
3	cyan
4	green blue
5	green
6	yellow
7	orange
8	red orange
9	red

Figure 7. Example Color-mapping algorithm.

Frame length sets the time resolution for DPX measurements. If the bitmap shows that a -10 dBm signal at 72.3 MHz was present for 10% of one frame's duration (5 msec out of 50 msec), it isn't possible to determine just from the DPX display whether the actual signal contained a single 5 ms pulse, one hundred 50 microsecond (μs) pulses, or something in between. For this information, you need to examine the spectral details of the signal or use another display with finer time resolution, such as Frequency vs. Time or Amplitude vs. Time.

Converting Occurrence Counts to Color

About 20 times per second, the grid values are transferred to the next process step, in which the z-axis values are mapped to pixel colors in the visible bitmap, turning data into information (Figure 7). In this example, warmer colors (red, orange, yellow) indicate more occurrences. The color palette is user-selectable, but for now we will assume the default "temperature" palette.

The result of coloring the database cells, Figure 8, according to the number of times they were written into by the nine spectrums, one per pixel on the screen, creates the spectacular DPX displays.

In addition to the choice of palette, there are z-axis scaling adjustments for Maximum, Minimum, and Curve. Maximum sets the occurrence value that will be mapped to the highest color in the palette. Minimum sets the occurrence value for the lowest color. In the "temperature" palette, the highest color is deep red and the lowest is dark blue. Occurrence values less than the selected Minimum are represented with black pixels, while pixels that exceed the selected Maximum are red in hue but somewhat transparent. Values between Maximum and Minimum are represented by the other colors of the palette.

☑ Show File:DPX Pulsed RF.dp

0.00 dBm

dB/div: 10.0 dB

RBW: 100 kHz

-100.00 dBm

CF: 488.27 MHz

Span: 10.00 MHz

DPX Spectrum Settings

Vertical

Scale: 100.00 dB

Position: 0.00 dBm

Horizontal

Scale: 10.00 MHz

Position: 488.27 MHz

DPX Bitmap (Signal Density)

Color: Temperature

Max: 100.000 %

Min: 0.000 %

Curve: 3

Figure 9. DPX spectrum display with DPX Bitmap (Signal Density) with default color curve setting.

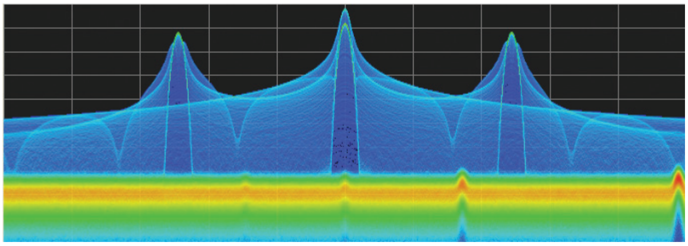


Figure 10. Selecting the Auto Color maximizes the spectrum of colors used to represent the current bitmap.

Adjusting the Minimum above the black default allows you to concentrate most of your color resolution over a small range of medium or higher occurrence rates to visually discriminate between different signals that have nearly equal probability values.

To see why adjustable color scaling is useful compare Figures 9 and 10. On the Scale tab, the Max control to is set to 100% in Figure 9. The range of colors now covers the full z-axis range of densities from 0 to 100%. The signals used to create this bitmap are fairly diffuse in both frequency and amplitude, so most pixels have low occurrence counts or density values, so the upper half of the color palette is unused.

When the **Auto Color** button is selected, this the Maximum control to the highest pixel value in the current bitmap in Figure 10. Now none of the available colors remain unused. The entire palette is mapped to the occurrence values present at the time the button is selected, providing better visual resolution for low densities. Selecting the **Autoscale** button in the DPX display scales all three axes based on current results.

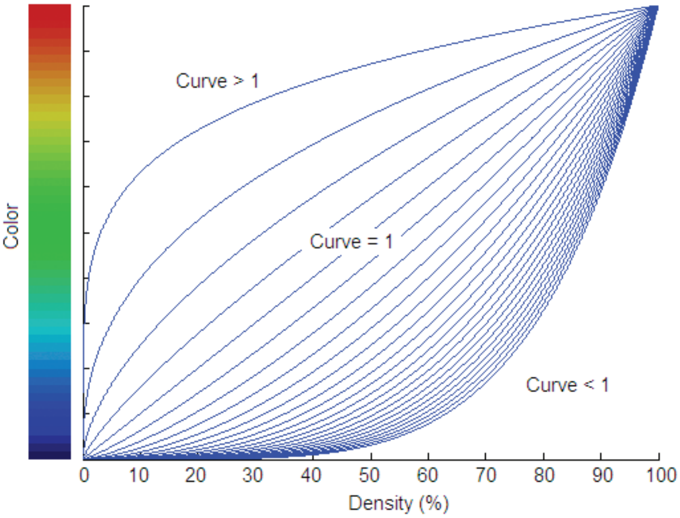
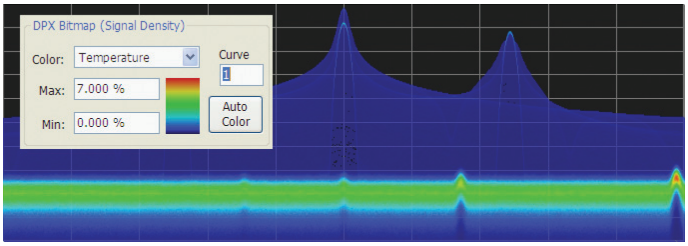


Figure 11. The representative color curve mapping for the "temperature" palette bitmap display.



DPX Bitmap (Signal Density)

Color: Temperature

Max: 7.000 %

Min: 0.000 %

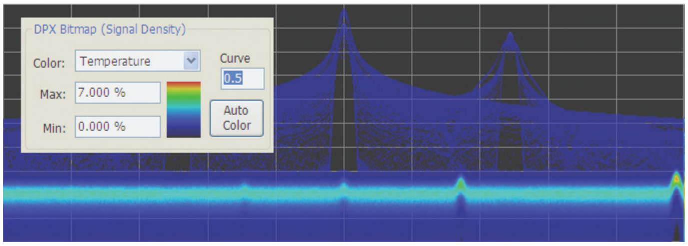
Curve: 1

Figure 12. Over a narrow Signal Density range, the color curve is set to 1.

Color Mapping Curves

The mapping between z-axis values and color doesn't have to be linear. The Curve control lets you choose the shape of the mapping equation. A Curve setting of 1 selects the straight-line relationship. Higher Curve numbers pull the curve upwards and to the left, concentrating color resolution on lower densities. Settings less than 1 invert the curve, moving the focus of the color range towards higher density values. Figure 11 shows the mapping curves.

Using the same example demonstrated in Figures 9 and 10 analyzing the on the impact of adjusting the color scale, the impact of setting the curve control can be observed. With the Curve control set to 1 in the Scale tab, shown in Figure 12, one can observe how the color palette illustration to the left of the Curve control changes as the Curve is varied. When the mapping is linear, the colors spread evenly across the full density range.



DPX Bitmap (Signal Density)

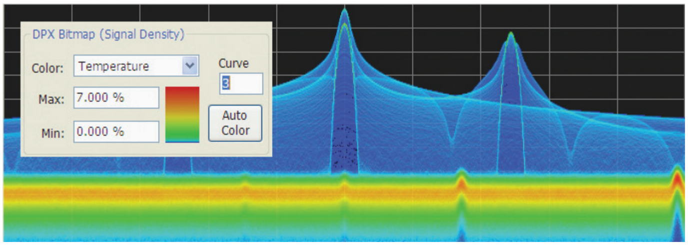
Color: Temperature

Max: 7.000 %

Min: 0.000 %

Curve: 0.5

Figure 13. Adjusting to values less than 1, decreases the contrast for viewing infrequent time-varying events using the “temperature” palette.



DPX Bitmap (Signal Density)

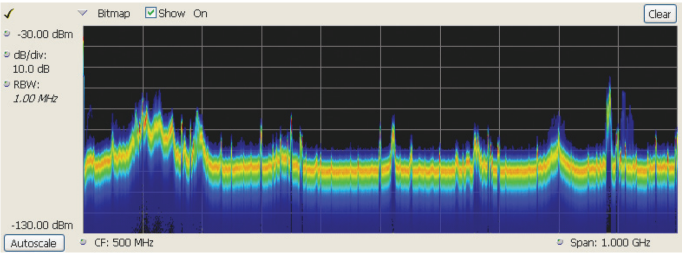
Color: Temperature

Max: 7.000 %

Min: 0.000 %

Curve: 3

Figure 14. For color curve setting greater than 1, better contrast can now be seen for infrequent pulse events using the “temperature” palette.



Bitmap ☑ Show On

-30.00 dBm

dB/div: 10.0 dB

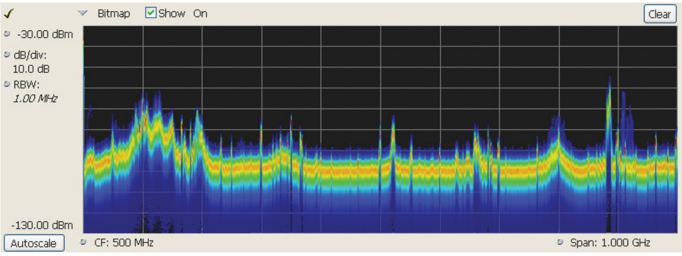
RBW: 1.00 MHz

-130.00 dBm

CF: 500 MHz

Span: 1.000 GHz

Figure 15. Off-air ambient signals over a 1 GHz span in the swept DPX display.



Bitmap ☑ Show On

-30.00 dBm

dB/div: 10.0 dB

RBW: 1.00 MHz

-130.00 dBm

CF: 500 MHz

Span: 1.000 GHz

Figure 16. During swept DPX operation, the Dwell time control enables the observation time of each segment step used to construct the composite DPX spectrum display.

When the Curve control is set to 0.5, as shown in Figure 13, the best color resolution is in the upper half of the density range, and only the dark blues are assigned to densities below 50%.

In Figure 14, the Curve control is increase to 3. The majority of colors shifts to the lower half of the density scale, but various shades of orange and red are still available for densities above 50%.

Swept DPX

DPX Spectrum is not limited in span by its real-time bandwidth. Like the regular Spectrum display, DPX Spectrum steps through multiple real-time frequency segments, building a wide-span display with line traces and the bitmap.

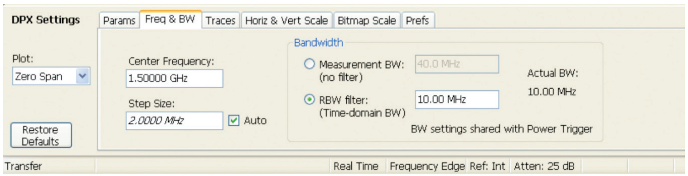
The analyzer “dwells” in each frequency segment for one or more DPX frames, each containing the results of up to 14,600 spectral transforms. Dwell time is adjustable, so you can monitor each segment of the sweep for up to 100 seconds before moving to the next step. While dwelling in a segment, the probability of intercept for signals within that frequency band is the same as in normal, real-time spans: 100% capture of events as short as 3.7 μsec.

A full pixel bitmap is created for every segment and compressed horizontally to the number of columns needed for displaying the frequency segment. Compression is done by averaging pixel densities of the points being combined together. The final swept bitmap contains a representation of the same pixel bitmap resolution, just like the non-swept bitmaps. Line traces are also created in full for each segment, and then horizontally compressed to the user-selected number of trace points for the full span.

A complex algorithm for determining the number and width of each frequency segment has been implemented. The variables in the equation include user-adjustable control settings like Span, RBW, and number of trace points, RF and IF optimization, and Acquisition BW. Installed hardware options also can affect the span segmentation. The number of segments ranges from 10 to 50 for each 1 GHz in a sweep.

A helpful piece of information for operators is the actual Acquisition Bandwidth used for capturing each segment. “Acq BW” is shown in the Acquire control panel on the Sampling Parameters tab. Acq BW is typically set automatically by the instrument, based on the needs of all the open displays, but can also be set manually. In either case, the displayed bandwidth is used for every frequency segment in the swept DPX display. The width of the segments is optimized for performance.

The entire instrument frequency range of many GHz can be covered in a DPX sweep. A simple control allows the amount of time DPX spends in each segment. This control, circled in Figure 16, can be set between 50 ms and 100 seconds.



Plot: Zero Span

Center Frequency: 1.50000 GHz

Step Size: 2.0000 MHz ☑ Auto

○ Measurement BW: (no filter) 40.0 MHz

● RBW filter: (Time-domain BW) 10.00 MHz

Actual BW: 10.00 MHz

BW settings shared with Power Trigger

Real Time | Frequency Edge | Ref: Int | Atten: 25 dB

Figure 17. DPX Time-Domain displays allow a time-domain RBW filter.

DPX Time-Domain Displays

Like the original DPX Spectrum display, the DPX Time-domain displays reinvent a previously-existing instrument capability by increasing the measurement rate by several orders of magnitude and adding powerful new DSP-based functions. These new time-domain displays employ the DPX processing engine to produce Amplitude, Frequency or Phase vs. time.

DPX Zero Span is a higher-performance version of the traditional zero-span feature of swept spectrum analyzers. DPX Frequency and Phase displays plot the input signal's instantaneous frequency and phase values as a function of time, in the same manner that Zero Span plots instantaneous amplitude values vs. time.

The preceding section of this primer, "Behind the Scenes: How DPX Spectrum Works", largely applies to the DPX time-domain displays as well. Just like DPX Spectrum, the DPX time-domain displays contain both bitmap and trace data. The bitmap display is color-graded with adjustable persistence, like the bitmap display for DPX Spectrum.

The fundamental differences between the DPX frequency- and time-domain displays are:

a) An FFT is not used for time-domain displays. Instead, the digitized data remains in the time domain. For the Frequency and Phase displays, the data is converted to frequency or phase.

b) Additional filtering can be done on the time-domain data, replacing the RBW filter used in DPX Spectrum.

c) Instead of being continuously generated as in DPX Spectrum, data for the time-domain DPX displays can be captured in response to trigger events, like an oscilloscope, though free-run is also supported.[*1]

d) The frame update rate decreases when triggers are occurring infrequently or the sweep time is long.

In many respects, the DPX time-domain circuit acts like an oscilloscope, plotting signal values over time. Familiar oscilloscope controls, such as vertical scale and position, sweep speed, zoom and pan, are present in DPX Time Domain displays, and work the same as they do in scopes.

Analyzing Amplitude, Frequency, or Phase

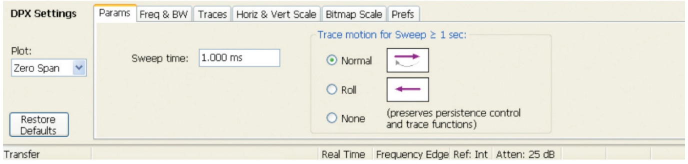
DPX time-domain processing starts with the same down-converted data used by DPX Spectrum and all the analyzer's other measurements. The input signal is in I-Q format after down-conversion. If additional bandwidth reduction is desired, a filter is applied to the I-Q data stream. Next, a CORDIC[*2] converts the I-Q data to phase and amplitude. For magnitude displays (dB, Volts, Watts) the amplitude data from the CORDIC is used to produce a time-domain waveform that is placed in the bitmap and traces.

For phase and frequency displays, only the phase data is used. Phase data from the CORDIC is initially converted to frequency by a simple differentiator, taking the difference from one phase sample to the next. All filtering and data processing is done on this frequency waveform, then for phase waveforms, the final step is an integration (taking the sum of all consecutive samples) to obtain the phase data.[*3]

[*1] In DPX Spectrum, the FFT runs continuously whether the trigger mode is Free Run or Triggered, and at the hardware level the DPX bitmap and traces are always being generated When the display is set to "DPX shows only trigger frames", the screen is only updated in response to trigger events and frames that don't contain triggered data are not shown. In DPX Time Domain, the bitmap and traces do not receive new data unless a trigger occurs or the display is in Free Run. This can affect both the display update rate and bitmap persistence.

[*2] Coordinate Rotation Digital Computer: a hardware-efficient algorithm for computation of trigonometric functions.

[*3] Waiting to compute the phase after all the filtering allows the phase display to wrap at +-180 degrees without affecting the signal passing through the filters.



Plot: Zero Span

Sweep time: 1.000 ms

Trace motion for Sweep ≥ 1 sec:

● Normal

○ Roll

○ None (preserves persistence control and trace functions)

Figure 18. The DPX Settings for time-domain displays allow the user to define the sweep time and trace motion for sweeps longer than 1 second.

Traces, Frames and Sweeps

Similar to DPX spectrum, traces are produced from the samples of incoming data, and these traces are written to a bitmap and color-graded according to their signal density over the period of a frame. One or more traces are used to create a frame, which is what the DPX engine sends to the display. Frames contain multiple traces when DPX is computing traces faster than the display can catch them. For longer time sweeps, frame length is either extended, or multiple frames are seamlessly stitched in time to create the display. Several methods for compressing and viewing the data are available as described below.

Traces and bitmaps

A trace is produced every time the DPX engine processes data, either as the result of trigger or upon receiving a free-run command from the triggering system. A trace has had bandwidth processing applied and its points have been converted to amplitude, frequency or phase. The traces are collected by the DPX engine and converted to the color bitmap for a frame. When sweep times are less than 1 second, traces are placed into a single frame and sent to the screen at a variable rate.

Frame Updates

New data frames are sent to the display system at a maximum rate of 20 times each second (50 ms/frame). If the sweep time is greater than 50 ms and less than 1 second, the DPX frame time is extended to match the sweep time. Like DPX Spectrum frames, every time-domain frame includes the bitmap and three user-selectable traces. The bitmap resolution of 801x201 is the same as for DPX Spectrum, but the time-domain traces are always 801 samples long, whereas trace length is adjustable in DPX Spectrum.

When a sweep (acquisition) takes 50 ms or longer, it isn't possible to have multiple sweeps in a single frame, because a single acquisition takes more time than an entire frame normally needs, and the frame ends up waiting for the acquisition to complete before it updates the screen. This is also the case when the time between trigger events is 50 ms or more.

Fast Sweeps

When sweeps (acquisitions) are happening faster than frames can be generated (20/sec, or 50 ms/sweep), each frame contains the results from multiple acquisitions. The acquisitions each yield one trace, and all the traces collected over 50 msec are combined into the frame's bitmap and line traces. The number of acquisitions in a single frame ranges from 1 to more than 2,500, depending on sweep time and trigger rate. This results a maximum trace update rate in excess of 50,000 waveforms per second for sweep times less than or equal to 10 μs.

If you want to capture one trigger event with each acquisition, with minimum dead time waiting for the next trigger to occur, set your sweep time a bit shorter than the time between trigger events.

Slow Sweeps

For "slow" sweeps (typically 1 second and longer), the frame rate is always 20/second. Multiple trace segments are placed end-to-end across the screen to create the complete sweep. This **incremental updates** mode creates the following three types of displays:

1. **Free Run / Normal Trace Motion** - The bitmap and traces are built up from the left edge of the graph. New points are added the right of previous points at the selected sweep rate. Once the display has filled, the display starts sweeping from the left edge again. New points overwrite those from the previous sweep, erasing the old data from memory.
2. **Free Run / Roll** - New bitmap and trace points appear at the right edge of the display and slide towards the left as new points arrive to displace them. Once data points have disappeared off the left edge of the graph, they are no longer in memory.
3. **Triggered** - While waiting for the trigger event, the display acts like Free Run / Roll, but with the new data points appearing at the trigger location rather than at the right edge of the graph. Points slide from the trigger location towards the left edge as each new point arrives. Once a trigger event is recognized, the post-trigger data points are added to the right of the trigger point, as in Free Run / Normal Trace Motion. When the trace has filled in all the way to the right edge of the graph, the sweep starts over again.

When DPX Time-Domain is in Free Run, the user can select either Normal or Roll trace motion (#1 or #2 above). In Triggered mode, method #3 is used to display the sweep.

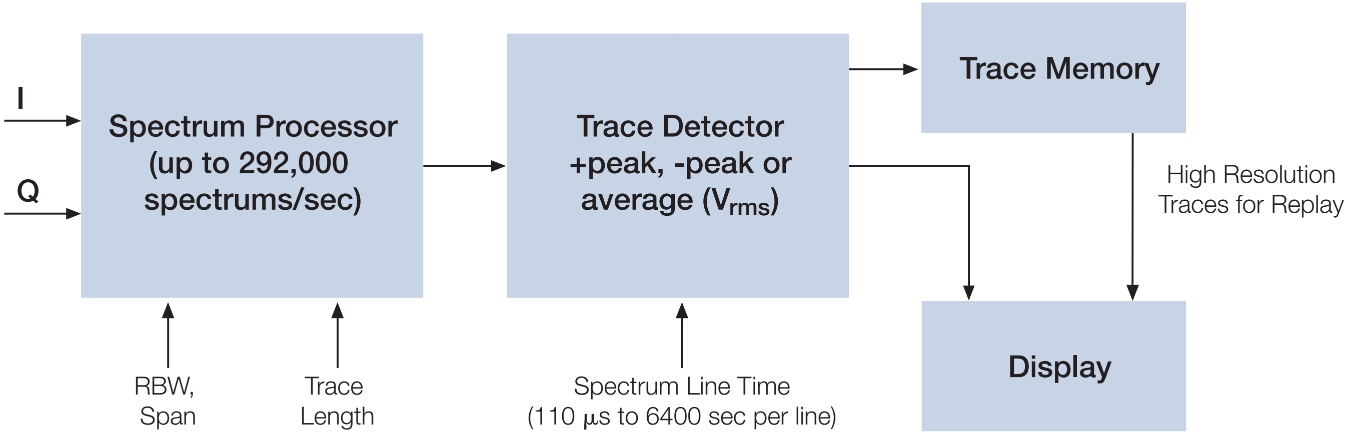


Figure 19. Block diagram of DPX Spectrogram processing.

DPX Spectrogram

Trace Lengths and Spectrum Line Time

All Tektronix real time signal analyzers can produce spectrograms of acquired data. This is done by moving an FFT window through the acquisition, and then producing a display with the horizontal axis of frequency, a vertical axis of time, and spectral amplitudes represented in a color map. This display can be extremely helpful when searching for low-level and infrequent transient signals. This type of spectrogram is limited by the available memory of the instruments. There are no instruments available that acquire seamless wide bandwidth (>100 MHz) acquisitions longer than a few seconds without the use of additional data storage devices and software. Processing and analysis of these large (multi-GB) data sets can take minutes to complete. During this processing time, the instrument is blind to any new changes in the signal.

By using the instruments real time hardware, the DPX Spectrogram can be measured to not have any gaps due to processing time. The DPX engine creates live, gapless spectrograms that can monitor signals continuously for days.

Real-time processing, diagramed in Figure 19, ensures that no signals are missed, and the time resolution of the spectrogram lines can be varied to trade time resolution for recording length.

When the DPX spectrogram display is open, the DPX engine continues to run at its normal spectrum processing rate, applying +peak, -peak or average (V_{rms}) detection to create traces at a user-selectable rate. For example, if the user requests peak results at 1 spectral line per second, the DPX engine will peak detect up to 292,000 spectrum traces before outputting a completed spectral line to the plot. Similarly, at 110 usec/line, the DPX engine produces the peak-detected result of 32 DPX spectrums in each line of output. In this way, the real time data is speed-reduced to rates visible to the human eye. To achieve the live update rate of the DPX spectrogram, a somewhat lower-resolution bitmap is used to drive the display during data collection. It contains 267 trace points per line. When the instrument is stopped for review and analysis, the DPX spectrogram is immediately re-drawn from traces stored in memory, with frequency resolution of up to 4001 trace points per line. The trace memory used for

Maximum Recording Time

(Span = Maximum Acquisition BW, RBW = Auto

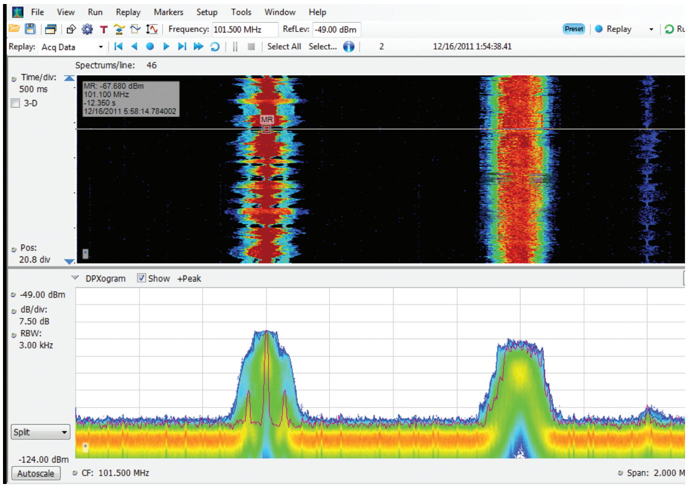
Spectrum Line Time Resolution	Trace Length 801 pts Max: 60Ktraces	Trace Length 2401 pts Max: 20Ktraces	Trace Length 4001 pts Max: 12Ktraces
110 μs	6.6 seconds	NA	NA
220 μs	13.2 seconds	NA	NA
550 μs	33 seconds	11 seconds	6.6 seconds
1 ms	60 seconds	20 seconds	12 seconds
5 ms	5 minutes	1.67 minutes	1 minute
10 ms	10 minutes	3.3 minutes	2 minutes
50 ms	50 minutes	16.7 minutes	10 minutes
100 ms	100 minutes	33.3 minutes	20 minutes
1 s	16.7 hours	5.6 hours	3.36 hours
10 s	166.7 hours	55.6 hours	33.4 hours
60 s	42 days	13.9 days	8.28 days
600 s	416.7 days	138.9 days	83.2 days
6400 s	4444.4 days	1481.5 days	888.8 days

Table 1. Relationship between Spectrum Line, Trace Length, and Record Time.

DPX spectrograms is of fixed size. The Table 1 shows the linear relationships between trace lengths, time resolution and recording time. The time resolution of the spectrum line influences the maximum recording time. Improved time resolution fills the memory faster. The Trace Length setting determines how many traces can be stored in this memory. In Table 1, you can see that increasing trace length decreases the maximum number of traces available, from 60,000 traces at 801 points/trace to 12,000 traces at 4001 points/trace.

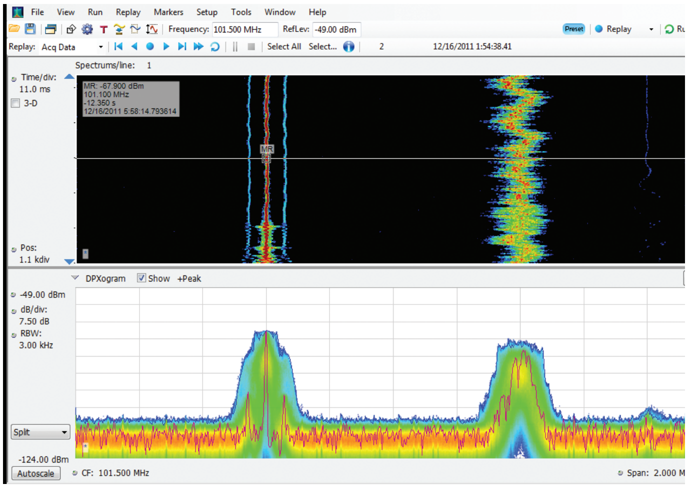
Display Detection and Compression

If high time resolution is required over long periods, the DPX spectrogram can include as many as 60,000 traces. To avoid scrolling through all these records, the user can adjust the time/division of the spectrogram (zoom out), and the display will be time-compressed using peak or average detection. When a signal of interest is seen, the user can zoom back in on the signal at its original time resolution.



Frequency: 101.500 MHz
RefLev: -49.00 dBm
Replay: Acq Data
Spectrums/line: 46
Time/div: 500 ms
Pos: 20.8 div
MR: -67.680 dBm
101.100 MHz
-12.350 s
12/16/2011 5:58:14.784002
-49.00 dBm
dB/div: 7.50 dB
RBW: 3.00 kHz
-124.00 dBm
CF: 101.500 MHz
Span: 2.000 M

Figure 20. Split display of DPX Spectrum and DPX Spectrogram displays.



Frequency: 101.500 MHz
RefLev: -49.00 dBm
Replay: Acq Data
Spectrums/line: 1
Time/div: 11.0 ms
Pos: 1.1 kdiv
MR: -67.900 dBm
101.100 MHz
-12.350 s
12/16/2011 5:58:14.793614
-49.00 dBm
dB/div: 7.50 dB
RBW: 3.00 kHz
-124.00 dBm
CF: 101.500 MHz
Span: 2.000 M

Figure 21. DPX Spectrogram display in uncompressed for detailed analysis.

Spectral Compression Example

DPX spectrograms are a fantastic tool for gapless capture and visual analysis over long periods. This is useful in both design applications and spectrum monitoring.

Figure 20 shows the example of a 2.5 second off-air FM-band signals on the DPX spectrogram, covering a period of 2.5 seconds. The DPX spectrogram traces are compressed such that there are 46 spectrums peak-detected to create one spectrum line. The spectral traces can be replayed, and individual traces can be selected for viewing in the DPX Spectrum plot. The figure shows the line at 05:58.140784 time on the DPX Spectrogram plotted as the orange spectral trace in the DPX Spectrum display. The point selected with the marker-line on the compressed spectrogram has a very brief period of no modulation, as seen on the orange trace in the displayed DPX spectrum. Once the instrument is stopped, the DPX Spectrogram display is expanded around this point on the spectrogram to reveal much more detail as the line compression is changed from 46 spectrums/line to 1 spectrum /line and the total displayed spectrogram time is reduced to 55 ms. Figure 21).

Guaranteed Capture of Fast Events

The main reason that swept-tuned and step-tuned spectrum analyzers can't provide 100% Probability of Intercept, POI, for a signal that isn't continuously present is that they spend only a short period of time tuned to each segment of their frequency span during each sweep. If something happens in any part of the span other than where it is tuned at that instant, that event will not be detected or displayed. There is also a period of time between sweeps, retrace time, during which the analyzer is not paying attention to the input signal. FFT-based analyzers, including vector signal analyzers, also miss signals during the time between acquisitions. Their POI depends on a combination of factors including span, number of FFT points, acquisition time, memory read/write time, and signal processing speed. Vector analyzers process information sequentially, so when read/write from data and processing is occurring, data is not being acquired.

RSAs, on the other hand, capture data across all frequencies within their real-time span during every acquisition. With Tektronix' exclusive Frequency Mask trigger and DPX Density trigger, POI increases to 100%, insuring capture of any spectral event matching the trigger definition. When operating in free run as a simple spectrum analyzer, the RSA has a POI similar to other FFT-based analyzers, with gaps between each acquisition. Processing is done concurrent with the acquisitions.

Span (MHz)	RBW (kHz)	Span/RBW Ratio	FFT Length	Spectrum/sec	MSD for 100% POI (µs)
110	10,000	11	1024	292,969	3.7
110	1000	110	1024	292,969	10.3
110	300	367	2048	146,484	20.5
110	100	1100	4096	73,242	41.0
110	30	3667	16384	18,311	163.9
110	20	5500	32768	9,155	327.7

Table 2. Minimum Signal Duration specifications for the RSA6000 Series spectrum analyzer with Options 110 and 200 under various combinations of control parameters.

Guaranteed Capture in DPX Real-time Spans

The DPX Spectrum display captures any signal that is at least 3.7 microseconds long and within the real-time bandwidth in a 10 MHz RBW. This performance is possible because the RSA computes up to 292,000 spectrum transforms per second. The faster the spectrum updates, the shorter the time between acquisitions and the greater the probability that any signal will be detected.

Table 2 shows the specified minimum signal duration (MSD) for 100% probability of intercept for various combinations of Span and RBW in DPX for a representative RSA model. As you can see, MSD is affected by multiple factors.

To demonstrate the POI in action, a challenging bi-stable signal is used. A CW sinusoid at 2.4453 GHz is unstable. Every 1.28 seconds, its frequency changes for about 100 µsec, then returns to normal. The duty factor of this transient is less than 0.01%.

Figure 22 shows a swept analyzer set up for a 5-second sweep of its MaxHold trace. It shows that there is something occurring around the signal. This sweep rate was empirically determined to be the optimum rate for reliable capture of this signal in the shortest time. Faster sweep times can reduce the probability of intercept and result in fewer intersections of the sweep with the signal transient.

The DPX display shown in Figure 23 shows the exact same event, also captured over a 5 second period. A lot more information can be discovered about the transient. It is obvious at first glance that the signal is hopping by about 3 MHz, with 1.2 MHz of frequency overshoot on transitions

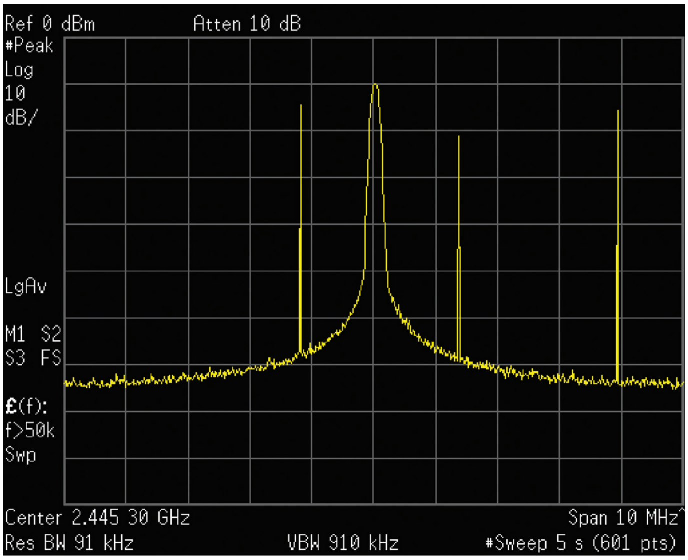

Ref 0 dBm
Atten 10 dB
#Peak
Log
10
dB/
LgAv
M1 S2
S3 FS
£(f):
f>50k
Swp
Center 2.445 30 GHz
Span 10 MHz
Res BW 91 kHz
VBW 910 kHz
#Sweep 5 s (601 pts)

Figure 22. Swept analyzer after 5 seconds. MaxHold trace.

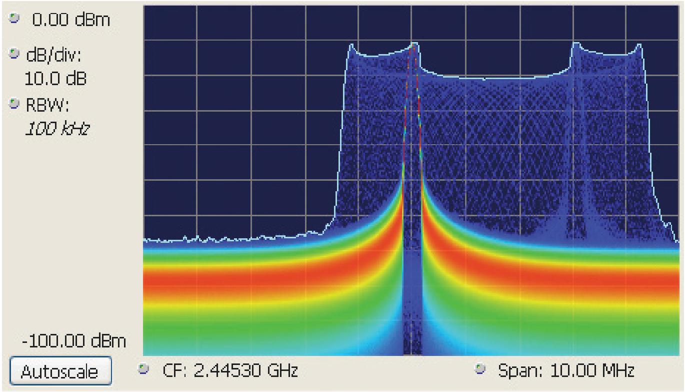

0.00 dBm
dB/div: 10.0 dB
RBW: 100 kHz
-100.00 dBm
CF: 2.44530 GHz
Span: 10.00 MHz

Figure 23. DPX spectrum display after 5 seconds. Bit map color mapping is "Temperature", to emphasize infrequent signals with cold colors. MaxHold trace is green.

Guaranteed Capture in DPX Swept Spans

Probability of intercept (POI) for signals within a single segment, while DPX is dwelling in that segment, is the same as for non-swept DPX operation (POI = 100% for events as brief as 3.7 microseconds). But just as in traditional swept analyzers, during the time the acquisition is tuned to any one segment, the analyzer is not monitoring signals in any of the other segments, so probability of capture in segments other than the current one is zero. Because of the wide real-time bandwidth, the number of segments needed to cover the span is much less than for swept analyzers, so the overall probability of intercept is significantly better for DPX sweeps.

Another factor affecting POI is number of trace points. The bitmap is always 801 points wide, but the line traces allow user selection for number of points. 801 is the default and the other choices are 2401, 4001, and 10401. Frequency transforms for traces containing more than 801 points take longer, and this lower waveform update rate increases the minimum signal duration proportionally. This caution applies for swept and non-swept operation. The trace length control is on the Prefs tab in the DPX control panel.

Guaranteed Signal Capture in DPX Time-Domain Displays

The DPX time-domain minimum captured signal duration can be calculated as 1/(Acquisition Bandwidth). Examples of this are 40 ns for a 25 MHz system, or 9.1 ns for a 110 MHz system, when no RBW is applied As with analog filters, the DPX digital filters have a time constant that increases as the filter bandwidth decreases. For example, a 1 µsec pulse can’t pass through a 1 kHz filter.

Sweeps per second

The number of time-domain waveforms/second displayed by the DPX engine is dependent upon several variables. Primary factors are:

- Sweep re-arm time. When the IF digitizer is running at 50 MSamples/sec, the re-arm time is approximately 6.5 µs for sweep speeds 16 µs or longer, increasing to 130 µs for the fastest sweep, 100 ns. At an IF digitizer rate of 150 MSamples/sec the rearm time is about 2.65 µs for sweeps speeds 5.33 µs or longer, increasing to 37.6 µs for 100 ns sweeps. The fastest sweeps have a longer rearm time due to the way the hardware computes the interpolated data points to put into the display.
- Trigger rate. For narrower RBWs the maximum trigger rate is slower, and is roughly the same as the RBW (e.g., with a 1 KHz RBW about 1000 triggers/sec are possible).
- The duration of the sweep. As an example, with no rearm time required and a trigger event occurring immediately at the end of each sweep, it's not possible to get more than 1000 waveforms/sec with a 1 ms sweep.
- At the end of a sweep, first the rearm time must occur, then the next trigger that is seen will start a new sweep.

Instrument state	Sweep Time	Max Waveforms/sec
Sample Rate = 50 MS/sec, RBW=10 kHz	100 ns	7750
	1 µs	69000
	10 µs	54200
	1 ms	990
Sample Rate = 150 MS/sec, RBW=20 MHz	100 ns	26550
	1 µs	74700
	10 µs	75900
	1 ms	910

Table 3. Shows the relationship between sample rate, sweep time and maximum waveforms/second for DPX Time-Domain views.

The complex interactions of these variables make it difficult to predict the maximum number of waveforms per second for all possible settings. The table above gives the waveform rate for several common sweep time and RBW combinations.

While these technical limitations are real, they do not come into play in normal use. When searching for the cause of unexplained behavior in a system under test, a narrow RBW is not typically selected, so as not to exclude possibly interfering signals at frequencies some distance from center. Likewise, a search for unknown transients starts at slower sweeps speeds, which provide a better overview of signal behavior. It is only after a suspicious signal has been identified that the sweep time is reduced to examine the event in detail.

While these technical limitations are real, they do not come into play in normal use. When searching for the cause of unexplained behavior in a system under test, a narrow RBW is not typically selected, so as not to exclude possibly interfering signals at frequencies some distance from center. Likewise, a search for unknown transients starts at slower sweeps speeds, which provide a better overview of signal behavior. It is only after a suspicious signal has been identified that the sweep time is reduced to examine the event in detail.

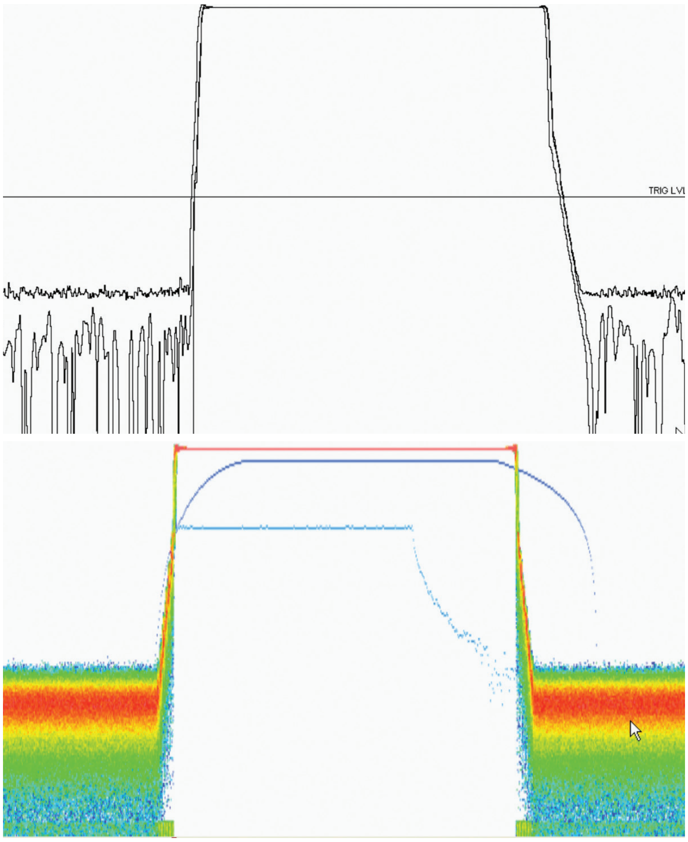


Figure 24. In this figure, conventional amplitude vs. time (Zero Span) on a spectrum analyzer is compared to DPX Zero Span. The signal contains three components, two of which occur very infrequently. In the same way that DPX spectrum illuminates elusive signals in the frequency domain, DPX Zero Span captures time domain signals at rates that are orders of magnitude faster than conventional signal analyzers.

As in DPX Spectrum, a major advantage of the DPX Zero Span, Frequency, and Phase bitmaps is the ability to see infrequent signals that would otherwise be hidden below other, higher-amplitude signals. Figure 24 compares a DPX Zero Span with a traditional zero span display of a pulse sequence. The malformed pulse apparent in the DPX graph occurs only 1 time for every 1000 good pulses. It is not visible at all in the other display.

In Figure 24, conventional amplitude vs. time (Zero Span) on a spectrum analyzer is compared to DPX Zero Span. The signal contains three components, two of which occur very infrequently. In the same way that DPX spectrum illuminates elusive signals in the frequency domain, DPX Zero Span captures time domain signals at rates that are orders of magnitude above conventional signal analyzers.

					4					
					6					
					13					
					18					
				1	3	1				
		1	2	4		4				
1	2	1	43	41	2	38	6	1	2	2
47	46	47	5	4	3	7	43	47	46	47
2	2	1			1		1	2	2	1

Figure 25. Grid showing cell counts after 50 waveforms. For each column, the sum of z-axis values is 50.

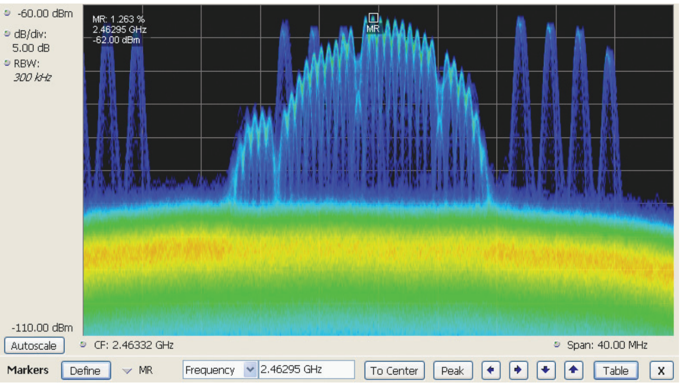
0%	0%	0%	0%	0%	0%	0%	0%	0%	0%	0%
0%	0%	0%	0%	0%	8%	0%	0%	0%	0%	0%
0%	0%	0%	0%	0%	12%	0%	0%	0%	0%	0%
0%	0%	0%	0%	0%	26%	0%	0%	0%	0%	0%
0%	0%	0%	0%	0%	36%	0%	0%	0%	0%	0%
0%	0%	0%	0%	2%	6%	2%	0%	0%	0%	0%
0%	0%	2%	4%	8%	0%	8%	0%	0%	0%	0%
2%	4%	2%	86%	82%	4%	76%	12%	2%	4%	4%
94%	92%	94%	10%	8%	6%	14%	86%	94%	92%	94%
4%	4%	2%	0%	0%	2%	0%	2%	4%	4%	2%

Figure 26. Grid after converting occurrence counts to percent density values. The sums of the cell density measurements within each column are all 100%.

DPX Density Measurements and Persistence Displays

“Density” is a measure of the amount of time during a defined measurement period during which signals are present within a particular area of the DPX Spectrum bitmap. A clean CW tone gives a 100% reading, while a pulse that is on for one microsecond out of every millisecond reads 0.1%. This section describes how density is computed from hit counts.

If we plot 41 more waveforms into the example grid we used previously in Figure 6 (in addition to the nine we already plotted), each column ends with a total of 50 hits (Figure 25).



MR: 1.263 %
2.46295 GHz
-62.00 dBm

dB/div: 5.00 dB
RBW: 300 kHz
CF: 2.46332 GHz
Span: 40.00 MHz
Frequency 2.46295 GHz

Figure 27. Grid after converting occurrence counts to percent density values. The sums of the cell density measurements within each column are all 100%.

The density for any one cell in a column is its own count value divided by 50, expressed in percent as shown in Figure 26. The math is very simple: a cell with 24 counts has a 48% density. In practice, instead of batches of 50 waveforms, we collect a frame of thousands of waveforms before each update to the density bitmap.

Measuring Density with Markers

Hit counts are cleared after every frame update, as long as Persistence is not turned on. The density value for any pixel is simply the percent of time it was occupied during the most recent 50 ms frame. Markers can be used to see the Density value for one or more individual points on the screen enabling measurements of the signal density at an interesting point in the DPX Spectrum display.

In Figure 27, Wireless LAN signals are analyzed in the presence of a Bluetooth radio signal in the 2.4 GHz ISM band. Frequency hopping radios, like Bluetooth, and WLAN pulses are represent a challenging signal.

With Persistence turned off, a marker is enabled to search for the peak signal recorded in the display. The marker readout in the upper left corner of Figure 27 shows the Density, Amplitude and Frequency for the pixel you selected with the marker. By adding additional markers, you can measure the signal density differences between two signals of interest at any point in time.

0%	0%	0%	0%	0%
0%	0%	8%	0%	0%
0%	0%	12%	0%	0%
0%	0%	26%	0%	0%
0%	0%	36%	0%	0%
0%	2%	6%	2%	0%
4%	8%	0%	8%	0%
86%	82%	4%	76%	12%
10%	8%	6%	14%	86%
0%	0%	2%	0%	2%

Figure 28a. Bitmap section showing density values.

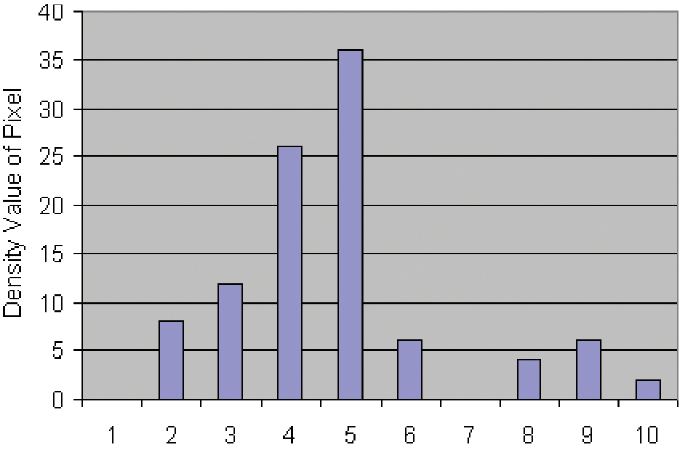


Figure 28b. Bar chart of the density values in the highlighted column of the bitmap.

Marker Peak Search in the DPX Bitmap

Markers on the DPX bitmap can search for peaks, similar to marker peak searching on spectrum line traces. For a human, it is pretty easy to discern "signals" in the bitmap picture. Your brain intuitively identifies strings of contiguous bright pixels. This isn't so easy for a computer. The first thing the RSA must do for any peak search is analyze pixel density values to identify apparent signals. Then it can sift through these density peaks for the amplitude peaks you want to find.

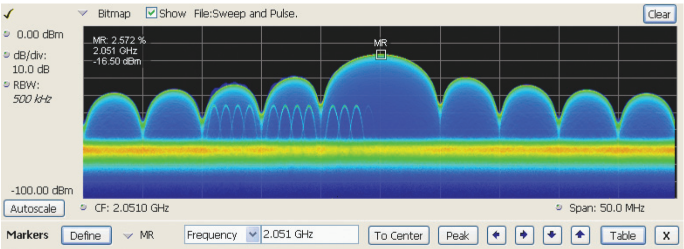
Z-axis density values for the pixels in each column of the bitmap are internally converted into histograms to find density peaks indicating the presence of signals. The table in Figure 28a shows the 5 middle columns from the example grid we used to illustrate density measurements in a previous section (Figure 26). Looking closely at the highlighted middle column, the density values for each pixel in this column are plotted on the y axis in the bar chart on the right of Figure 28b. The bar chart x axis is bitmap row number, numbering from the top of the table.

Assume that Density Threshold is set to 5% and Density Excursion to 5% also. Starting with x=1 in the bar chart, test each bar against the threshold. The threshold criteria is met at x=2. Keep testing until you find a bar that is shorter than the previous bar by at least the Excursion setting. In this case it is x=6. This tells us that a "signal" covers rows 2 through 5. Its density peak is at row 5.

Now you can look for another peak. Continue looking at bars to the right and you will find a density value at row 9 that meets the threshold criteria, but since there are no bars to the right of it that meet the excursion criteria, we can't declare row 9 a signal because it fails to meet the excursion criteria. If row 1 had 1% density, then row 9 would be a density peak.

Once density peaks are found for all columns in the bitmap, we can start looking for the amplitude peaks. When the **Peak** button is selected, the analyzer checks the histograms of every column in the bitmap and finds the density peak with the highest amplitude. The amplitude search has its own versions of Threshold and Excursion settings, but in dBm and dB units. When **Next Peak Down** command is given, the search will scan inside the current column for the next density peak. **Next Peak Right** examines each column to the right of the current marker location to locate density peaks that also meet the amplitude peak criteria.

To demonstrate the advantages of marker peak search, we will use the time-multiplexed signals showing multiple amplitude levels from our previous example early in this primer.



File:Sweep and Pulse.

0.00 dBm

dB/div: 10.0 dB

RBW: *500 kHz*

-100.00 dBm

MR: 2.572 %
2.051 GHz
-16.50 dBm

CF: 2.0510 GHz

Span: 50.0 MHz

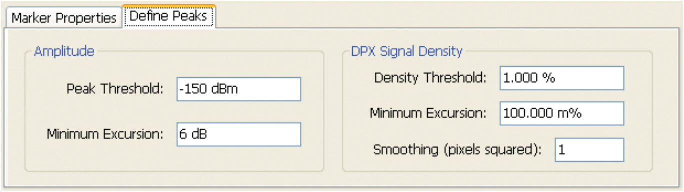
Frequency: 2.051 GHz

Figure 29. Marker selected to Peak. The reference signal density, frequency, and amplitude are shown on the right hand part of the DPX spectrum display.

A reference marker is placed on the peak signal in Figure 29. The peak signal is the highest-amplitude point that also exceeds the density threshold.

The Marker Toolbar, at the bottom of Figure 29, allows easy navigation of peak signals (**Peak Left, Peak Right, Next Peak Up, or Next Peak Down**). Selecting the arrow keys enables the marker to search for amplitude/density peaks at other frequencies, while the **Next Peak Up** and **Next Peak Down** arrows enable the marker to search for other high-density points at the same frequency.

In the Define Markers control panel to the Define Peaks tab, Figure 30, you can control the density threshold and excursion controls to see how they affect search behavior. The amplitude threshold and excursion controls also apply to DPX marker searches. Smoothing keeps the marker from finding multiple peaks within the same apparent signal by averaging an adjustable number of pixel densities together, but it does not affect the single-pixel measurement readout displayed by the marker.



Amplitude

Peak Threshold: -150 dBm

Minimum Excursion: 6 dB

DPX Signal Density

Density Threshold: 1.000 %

Minimum Excursion: 100.000 m%

Smoothing (pixels squared): 1

Figure 30. Amplitude and Signal Density controls can be selected to define Peak signals.

Density Measurements over an Adjustable Area ("The Box")

The density for a single pixel is its ratio of actual hits vs. possible hits over a defined time period, and that markers display these values. For measuring density over an area larger than one pixel, Option 200 includes a measurement box you can resize and drag around in the DPX Spectrum display with your mouse or finger.

If you could make the box so narrow that it contained only points within a single column of pixels, the density of this area would be the sum of the included pixels' density values. For example, if the box was three pixels tall and the density values for these pixels were 4, 2, and 7% respectively, the overall density for the three-pixel area would be 13%. Imagine a box one pixel wide and as tall as the graph. Assume that the input signal's amplitude was such that all hits fell at or near the vertical center of the screen. Since 100% of the waveforms written to the bitmap passed through the box, the density for the box is 100%.

$$\textit{Density of an area} = \frac{\textit{(Sum of densities of all pixels)}}{\textit{(Number of columns)}}$$

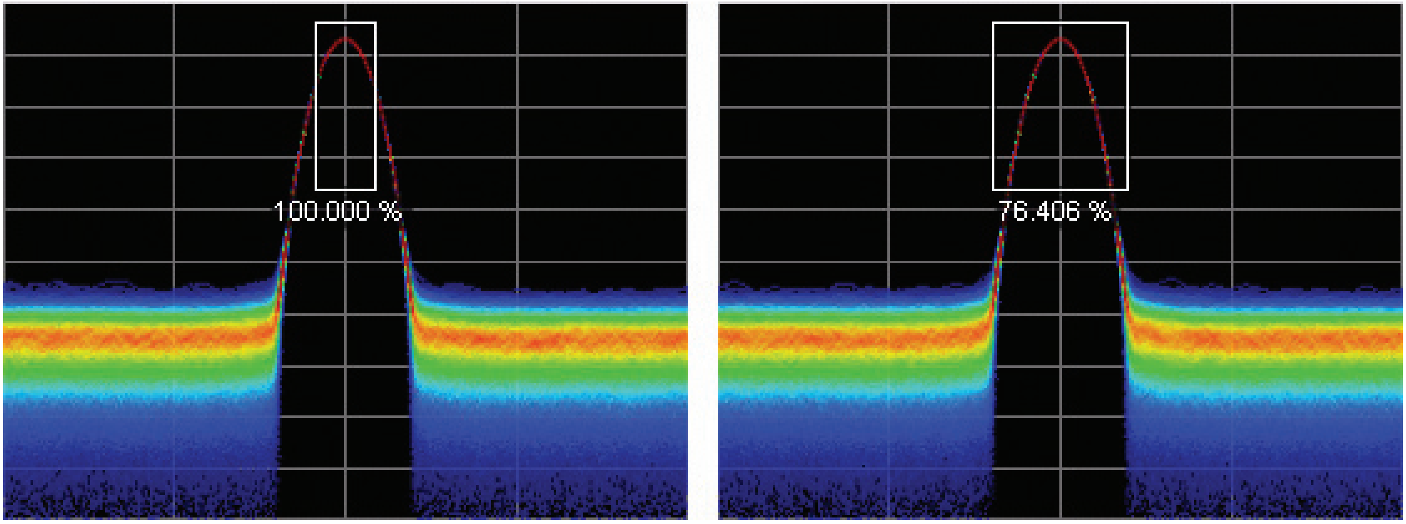
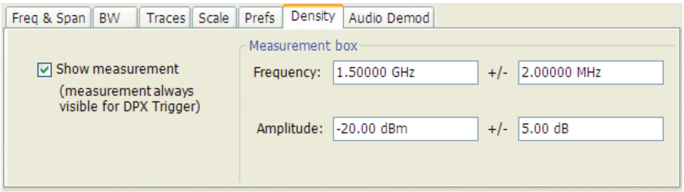


Figure 31. Density of signals defined within an area. Left: Correct measurement of a CW signal. All columns in the box include the signal. Right: Incorrect analysis window. The measurement is accurate, but probably not what you expected. Some columns in the box contain no hits, so they contribute zeros to the calculation of average density.

When you widen the box to cover a broader range of frequencies, software computes the density sum for the included pixels in each column inside the box. The aggregate density value for this box is the average density, calculated by adding the column density sums then dividing by the number of columns. For a 100% result, there must not be any hits above the top edge of the box or below its bottom edge. In other words, every waveform drawn across the graph entered the box through its left side and exited the box through its right side, with no excursions out the top or bottom. Figure 31 demonstrates this principle on a CW signal. As you can see on the left hand side, no amplitudes exist above or below the box; the density of the signal is 100%. On the right hand side, there are signals below the box, therefore the density is less than 100%.

The density measurement box' vertical size and location are always set in dB and dBm, no matter what units you have selected for measurements. (Amplitude control panel > Units tab) The box is not draggable when the selected units are linear (such as Amps, Volts, Watts…), though you can still adjust its size and location using the Frequency and Amplitude controls in both the DPX Settings > Density and Trigger > Event tabs. Since the vertical scale is non-linear, a box of constant amplitude changes visual height as it changes vertical position, a disconcerting effect if you are trying to drag it.



☑ Show measurement
(measurement always visible for DPX Trigger)

Measurement box
Frequency: 1.50000 GHz +/- 2.00000 MHz
Amplitude: -20.00 dBm +/- 5.00 dB

Figure 32. DPX Density control panel is used to define the area of interest for DPX density measurements.

To measure the average signal density over a defined area, you can define the area in the DPX Settings control panel > Density tab shown in Figure 32.

A readout will appear somewhere in the graph. If the box is off-screen, the readout will be accompanied by an arrow pointing towards the invisible box. Grab this readout with your mouse or finger and drag the density readout to the area you want to measure.

To adjust the box size, a mouse is the easiest way to drag the sides and corners of the rectangle. For precise settings, use the knob, arrow keys, or keyboard to adjust frequency and amplitude values for the rectangle. These controls are located in the right half of the Density tab in the control panel. You can also compare single-pixel densities measured with a marker against average densities measured over a larger area.

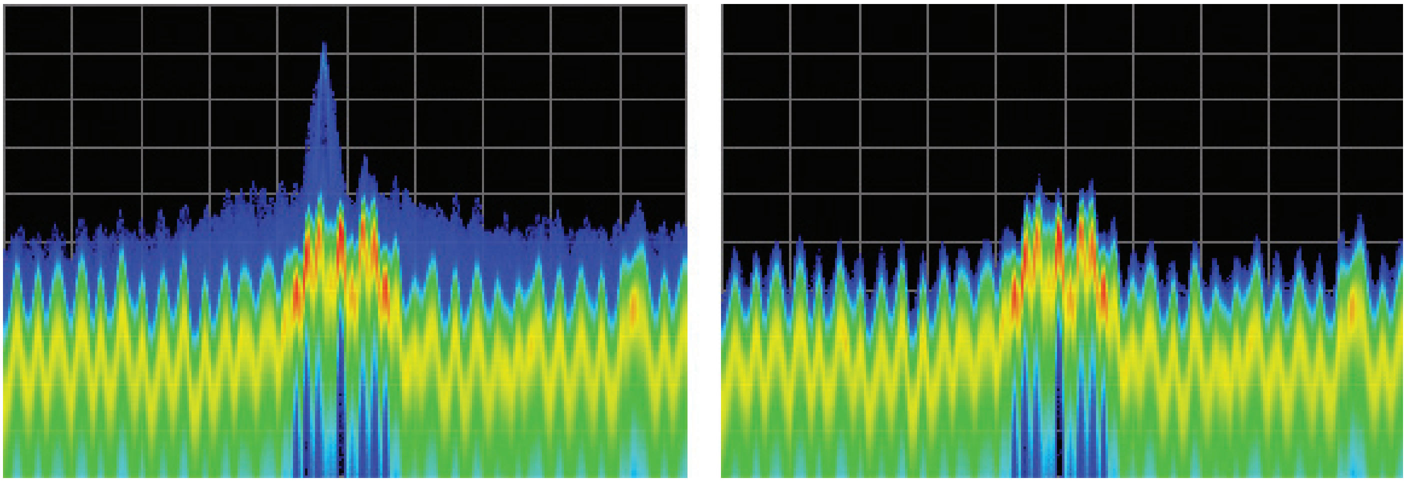


Figure 33. Example of fast transient discovery with and without variable persistency truned on. The display on the left, with variable persistence of 10 seconds, the occasional sub-second transient that spikes up above the normal signals is held in the display rather than disappearing as soon as the signal goes away. The display on the right, with persistence turned off, you have to watch the display continually to see the brief signal.

Persistence

Previous sections of this primer have assumed that persistence was not applied to the DPX bitmap. Without persistence, hit counts in the grid are cleared after each frame update. Now we will describe how persistence modifies this behavior, starting with infinite persistence because it is simpler than variable persistence.

Hit counts are not cleared between frames if infinite persistence is enabled. When the instrument is set up for continuous acquisitions, hits keep collecting until you stop acquisitions or click the **Clear** button above the DPX display. Software keeps track of the total number of waveforms computed during the entire collection period. Density equals the total number of hits to a cell divided by the total number of waveforms.

Variable persistence is trickier. A single-occurrence signal shown in the bitmap does not disappear suddenly upon the next frame update, nor does it linger forever. It fades gradually away. The user sets a time constant for the Dot Persistence control which determines how long it takes for signals to fade. Fading is accomplished by reducing the hit count in every cell, after each frame update, by a factor based on the persistence time constant. The longer the time constant, the less the hit counts are reduced.

Not only are single-occurrence signals allowed to remain in the display for awhile by variable persistence, additional hits keep piling on. The result is that cell values are no longer pure hit counts; they include counts due to new hits from waveforms plus proportionally reduced counts from prior frames. As part of translating hit counts into density values, a new software algorithm uses a finite-series equation to discriminate between the effects of persistence and the arrival of new hits. The inflationary effects of persistence on cell counts are removed, so density readings represent the true ratio of actual hits to possible hits over the persistence interval.

The density computation for variable persistence is a very good estimate of true signal density, with errors of less than 0.01%. For exact density measurements, use either no persistence or infinite persistence.

Another subtlety of persistence is its smoothing effect on the density measurement of intermittent signals. Consider a pulse that is on for 10 msec and off for 90 msec of each 100-msec cycle. We'll make the simplifying assumption that the pulse ON time always falls entirely within a single DPX frame update (50 msec). If persistence is not applied, the density measurement is computed on each individual frame. The results will be 20% for each frame containing the ON time and 0% for the other frames. If infinite persistence is enabled, however, the density measurement will settle to 10% after the second frame, and remain at this value for as long as the pulsing continues. With persistence, the density is effectively computed over many frames.

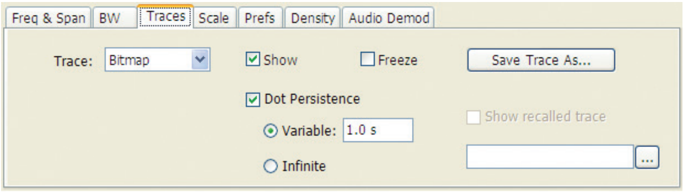
	RSA5/6000 Series Standard	**RSA5/6000 Series Option 200**
Hit Count	16-bit integer	36-bit custom float (equivalent to 33-bit integer)
Maximum Hit Count	2^{16} (65,536)	2^{33}
Minimum Time until Overflow (for pixels with 100% density)	<50 msec	8.1 hours

Figure 34. Comparison of DPX z-axis resolution and its affect on saturation.

Persistence Effects on Density

Persistence does not alter colors in a density-based bitmap. Its effect is to extend the amount of time over which densities are calculated, leaving signal events visible for the persistence Before the introduction of density measurements and extra-long hit counters, persistence caused colors to “bloom”, becoming more and more intense over time as the hit counts increased. Longer persistence intervals caused increased blooming, turning crisp signals into fat red stripes. When hit counts are converted to density values (requires Option 200 on RSA5/6000 Series), the display is not subject to this effect. As long as the input signals maintain reasonably stable repetition rates and duty ratios, their density values will also remain stable despite ever-increasing hit counts in the underlying grid cells.

If you are accustomed to the original hit-count-based persistence displays, it may seem counterintuitive that repeating signals in a density-based bitmap will not get brighter and redder over time with infinite persistence. A quick review of the density algorithm explains why: the hit count is divided by the total number of waveforms over the persistence interval. For example, if a signal occupies a pixel 50% of the time over a period of 15 minutes, the density reading will be 50% throughout the entire 15 minutes, though the underlying hit count is steadily increasing.



Trace: Bitmap

☑ Show

☐ Freeze

☑ Dot Persistence

● Variable: 1.0 s

○ Infinite

☐ Show recalled trace

Figure 35. Comparison of DPX z-axis resolution and its affect on saturation.

Z-Axis Resolution

Another factor that can cause color bloom is overflow of the hit counters. If a pixel could only count up to 1000 hits, its density and color values would clip at 100% after just 1000 hits, even if waveform points continue to arrive in the same pixel location. With waveform points being written to the bitmap at rates approaching 300k/sec, counts add up really fast for highly-repetitive signals. Deeper counters permit higher hit counts, so overflow happens much later, as shown in Figure 34.

Clipping due to overflow of the counters in one or more cells will not occur until hours have passed, or even days.

One more benefit to having deeper hit counters is better visual resolution of density. RSAs with the highest-performance DPX hardware installed use floating-point numbers to count hits, allowing us to count billions of waveforms while retaining one-hit resolution, providing better than 99 dB of dynamic range for density measurements. Density measurements in μ%, n%, and even f% ranges are quite possible for extremely rare signals captured with infinite persistence.

With straight-line mapping between density and color (Curve setting of 1), resolution is fixed by the number of colors in the palette. For non-linear mappings (Curve settings higher or lower than 1), most of the colors are concentrated at either the low or high end of the density scale, so you can visually discriminate finer differences between density values in that range.

Persistence Adjustments

Dot Persistence can be enabled for the “Bitmap” trace using the Settings control panel. The Persistence can be displayed as Infinite or Variable. For Variable Persistence, you can select the fading time of signals in seconds as shown in Figure 35.

By adjusting the time constant and observe display behavior with both short and long persistence intervals. If your signal is continuous rather than pulsing or hopping, you can see the effects of persistence by turning the signal on and off.

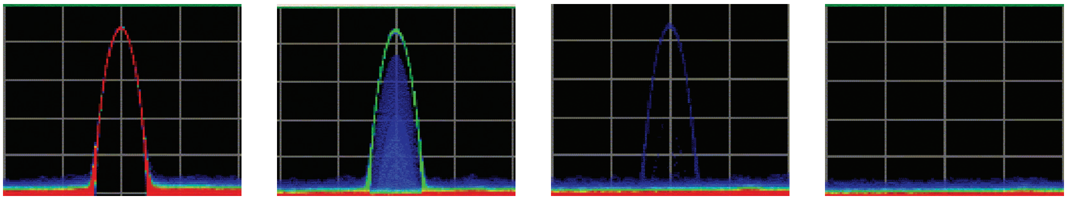


Figure 36. With variable persistence, a brief CW signal captured by DPX remains in the display for an adjustable period of time before fading away.

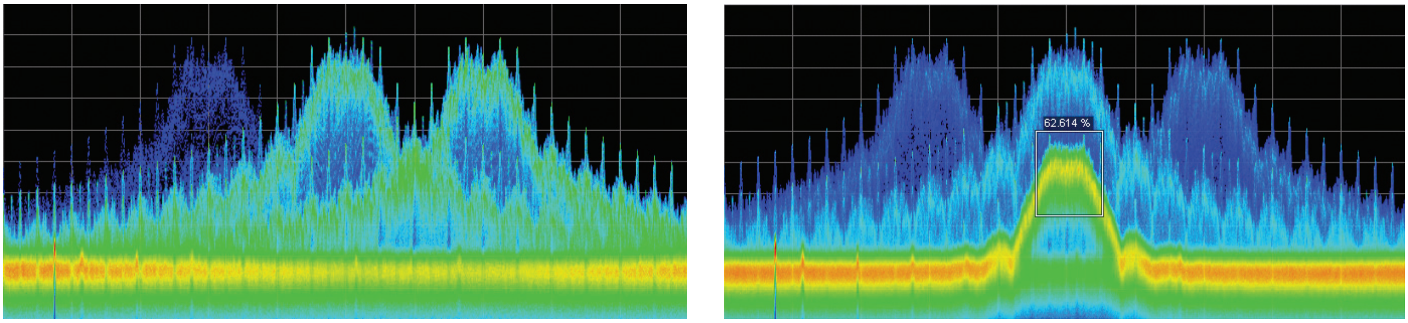


Figure 37. Example of Density Trigger Function. Left: A free-run DPX spectrum display showing pulses with varying frequency. Occasionally, a short pulse in the middle appears for a splut instant, but it is hard to capture it with just a Run/Stop button. Right: The triggered DPX displays shows the low-amplitude pulse that was not apparent in the untriggered display. The analyzer was set to trigger whenever the average density in the user-drawn box measured 50% or higher.

Figure 36 demonstrates the observed behavior of variable persistence when a CW signal, represented in the first frame, is turned off using the temperature color palette. Even if the event was instantaneous, within a single frame, depending on the duration settings of the variable persistence, you will observe the single change to lower densities of the respective color palette until the signal disappears.

Bitmap Persistency in Time-Domain Displays

Bitmap persistence holds bitmap display points over from one frame to the next. Infinite persistence holds points at their original hit counts over time, only updating a point if it has a higher value in a later frame.

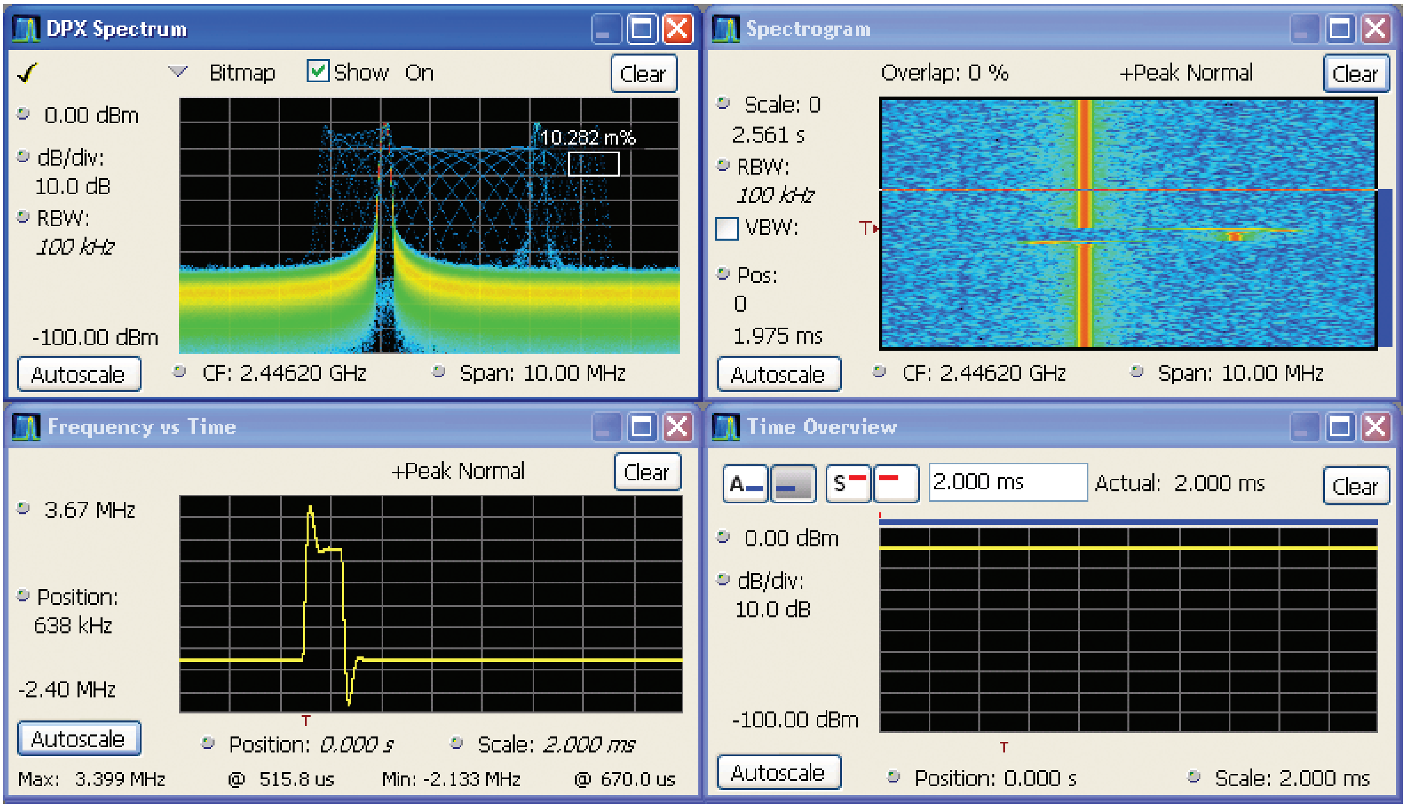
When Variable Persistence is selected, a decay cycle is done after each frame. Data points aren't erased after each frame, as when persistence is turned off, but they fade over time. The persistence time constant is based on a 20 frames/second reference. When frames occur at a slower rate, visible persistence increases proportionately.

Persistence controls are disabled for long, multi-segment sweeps with trace motion enabled. In this condition, pixel values (color) are held constant for the duration of the sweep. When the next sweep occurs, its new pixel values overwrite the previous sweep's bitmap. Adjustable persistence can be enabled for these long sweeps by selecting "None" as the setting for Trace Motion. This has the effect of collecting all data for a long sweep into a single frame where variable persistence can be correctly applied. However, the screen only updates after all of the trace data has been collected (e.g. a 10 second sweep time updates the screen once per 10 seconds).

DPX Density Trigger

The standard DPX display shows you a clear picture of transients and other hard-to-find signals. The new version of DPX in the RSA5/6000 Option 200 goes well beyond helping you discover these difficult to find signals by actually triggering on their appearance to capture them into acquisition memory for in-depth analysis. If you can see it in the DPX bitmap, you can trigger on it. It is as easy as pointing and clicking.

Other trigger methods can detect signals that exceed an amplitude threshold, or even a sophisticated amplitude-vs.-frequency mask, but they can't find a signal at a particular frequency if another signal of higher amplitude is sometimes present at that same frequency. The Runt triggering addresses some of these signal-under-signal cases, but not all. As shown in Figure 37, only the DPX Density trigger can discriminate signals within a precise amplitude-frequency range without the operator having to know any characteristics of the target signal besides where it might show up in the DPX Spectrum graph.



DPX Spectrum: ☑ Show On

0.00 dBm

dB/div: 10.0 dB

RBW: 100 kHz

-100.00 dBm

CF: 2.44620 GHz

Span: 10.00 MHz

Spectrogram: Overlap: 0 % +Peak Normal

Scale: 0

2.561 s

RBW: 100 kHz

☐ VBW:

Pos: 0

1.975 ms

CF: 2.44620 GHz

Span: 10.00 MHz

Frequency vs Time: +Peak Normal

3.67 MHz

Position: 638 kHz

-2.40 MHz

Position: 0.000 s

Scale: 2.000 ms

Max: 3.399 MHz @ 515.8 us Min: -2.133 MHz @ 670.0 us

Time Overview: 2.000 ms Actual: 2.000 ms

0.00 dBm

dB/div: 10.0 dB

-100.00 dBm

Position: 0.000 s

Scale: 2.000 ms

Figure 38. The analyzer triggered when the density in the DPX measurement box exceeded the threshold set by Trigger On This. You can see in the Spectrogram and Frequency-vs-Time displays that the signal event which caused the trigger was a quick frequency hop. The Time Overview shows that the signal amplitude never changed, so a power level trigger would not have worked.

The DPX Density trigger uses the same screen-based measurement box as the DPX Density measurement. While the target signal is absent, the density measurement characterizes the "normal" signals within the box. When the target signal finally appears, the density value increases. The trigger system monitors the density measurement and activates a trigger whenever the density value exceeds the adjustable density threshold. The only thinking you have to do is to set this threshold to a level somewhere between the normal density readings and the density due to the trouble-making signal. However, the instrument software can compute the threshold value automatically.

Trigger On This™

The "Trigger On This™" function allows you to point and click to set up the DPX Density trigger. Using an example of a time-varying signal, by right-clicking on a spot within the DPX Spectrum display, or pressing and holding your finger on the RSA5/6000 Series touchscreen display for about a second, a menu selection will appear. Selecting "Trigger On This", configures a DPX Density box will appear and enables the DPX Density Trigger to automatically adjust the threshold. The DPX Spectrum display will now only update whenever the automatic threshold is exceeded. Subsequently, if needed for your signal, open the Trigger control panel to adjust the density threshold or the size of the measurement box until the event is reliably captured.

Automatic Threshold Adjustment by Trigger On This™

The trigger density threshold automatically set by Trigger On This is 80% of the measured value. If the signal was present at the moment you selected Trigger On This, the threshold will be 20% less than the signal density, so the next time the signal is present long enough (or present enough times) to exceed the threshold density, it will cause a trigger. If the signal happened to be missing when you selected Trigger On This, the threshold value will be even lower. If you clicked in a part of the display with no signal activity at all, the threshold will be set to zero. Any signal that shows up here will fire the trigger, as shown in Figure 38.

DPX Density Trigger Timing

The time resolution for DPX density measurements is the frame length, around 50 msec. A basic implementation of the DPX Density trigger concept is also frame-based, so a trigger event that occurs anywhere within a frame will not be recognized until the end of the frame. Therefore, the worst case trigger uncertainty is 50 msec.

DPX Density trigger doesn't always have to wait until the end of a frame before firing. For the common configuration of triggering when the measured density is higher than the threshold, the density measurement in the trigger can be computed many times within each frame and it can fire the trigger as soon as the threshold is exceeded.

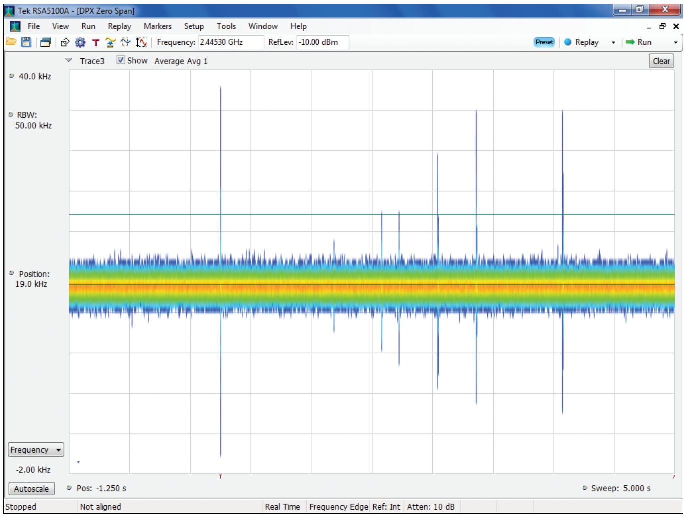
Consider the case where the threshold is zero. As soon as a single waveform causes a hit within the measurement box, we know that the density is greater than zero. It takes a little longer to test for a 5 or 10% density, and even more time for thresholds at or near 100%.

The DPX Density trigger can also be set to fire when the measured density is below the threshold value. This is useful when you suspect that your signal is missing some of the time. For a signal that is supposed to be CW, you can set the trigger controls to acquire when the density measurement of the signal peak drops below 100%. When using the “lower than” form of the DPX Density trigger, the time resolution is one frame because of the following logic: We can't be sure the actual density is less than, say, 15% until at least 85% of the full test time has elapsed. In order to keep things simple and fast in the trigger module, the RSA just waits until the end of each 50-msec frame to do the “lower than” comparisons.

Persistence and DPX Density Trigger

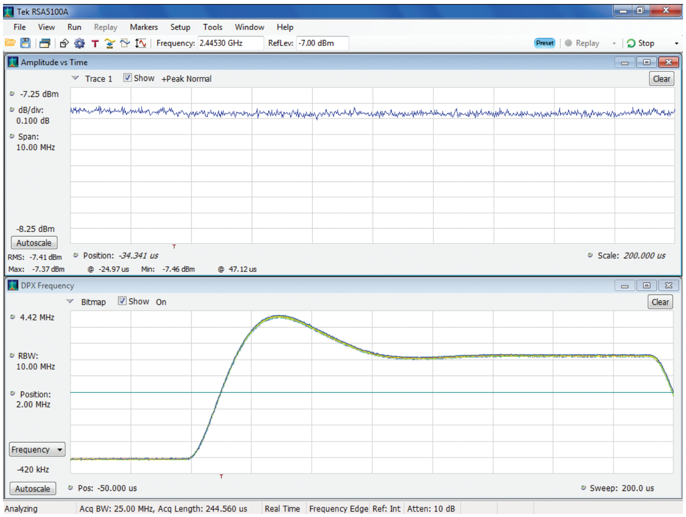
The smoothing effect of persistence on density measurements can help in determining a good threshold value. With persistence turned off, an infrequent signal's density reading jumps between higher and lower values as it turns on and off, and it can be hard to read these flashing numbers. By turning persistence on, you instruct the instrument to average the density over a longer time period. This density result is somewhere between the ON and OFF density values - the very definition of a good trigger threshold.

Unlike the DPX Density measurement, the DPX Density trigger is not affected in any way by persistence. Density calculations in the trigger system are made with hit count data received from each individual DPX frame, before any persistence is applied. Even when the density measurement reading in the display is averaged over many frames due to persistence, the trigger is computing density for each frame and comparing these quick snapshots against the threshold setting.



Frequency: 2.44530 GHz
RefLev: -10.00 dBm
Trace3 ☑ Show Average Avg 1
40.0 kHz
RBW: 50.00 kHz
Position: 19.0 kHz
-2.00 kHz
Pos: -1.250 s
Sweep: 5.000 s
Stopped
Not aligned
Real Time
Frequency Edge
Ref: Int
Atten: 10 dB

Figure 39. The frequency vs. time display combined with frequency edge triggering used to capture transients on a CW signal. Centered at 2.4453 GHz, the DPX frequency vs. time display has been set for a sensitivity of 42 kHz full-scale, allowing the display of small transients. The green trigger line on the display is the frequency at which a trigger will be generated. The time scale of the display is 5 seconds. As is seen in the illustration, a transient has occurred at the trigger point, and several other transients occurred in the 3 seconds following the initial anomaly.



Frequency: 2.44530 GHz
RefLev: -7.00 dBm
Trace 1 ☑ Show +Peak Normal
-7.25 dBm
dB/div: 0.100 dB
Span: 10.00 MHz
-8.25 dBm
Position: -34.341 us
Scale: 200.000 us
RMS: -7.41 dBm
Max: -7.37 dBm @ -24.97 us
Min: -7.46 dBm @ 47.12 us
Bitmap ☑ Show On
4.42 MHz
RBW: 10.00 MHz
Position: 2.00 MHz
-420 kHz
Pos: -50.000 us
Sweep: 200.0 us
Analyzing
Acq BW: 25.00 MHz, Acq Length: 244.560 us
Real Time
Frequency Edge
Ref: Int
Atten: 10 dB

Figure 40. A frequency transition from a PLL circuit is recorded, using the Frequency Edge Trigger to capture the center of the transition point. In the lower display, frequency vs. time is displayed, and the line at the center of the display is the Frequency Edge trigger level. The upper display is amplitude vs. time with a vertical scale of 0.1 dB/division, showing that there is no amplitude transient on which to trigger.

Frequency Edge Trigger

The innovative Frequency Edge trigger is implemented in the same FPGA as the DPX processing engine. It complements the other frequency-based triggers, Frequency Mask and DPX Density. All three of these are useful for triggering the main instrument acquisitions, but the new Frequency Edge trigger is the only one of the three that allows the DPX time-domain displays to run concurrently with it. The Frequency Edge trigger can be used to trigger on planned frequency transitions, or transient frequency anomalies that may occur. Figure 39 is an example of using the Frequency Edge trigger on a mechanical transient.

Frequency Edge is the most straightforward frequency-based trigger because Frequency Level is the only trigger criteria users need to adjust for each new setup. It is very much like the Power Level trigger, in that a trigger event is recognized each time the signal crosses the Level value. The difference is that the Frequency Edge trigger's level control is set in Hz relative to Center Frequency rather than in dBm power units. Users can enter a numeric value for Frequency Level, and they can see the trigger threshold line track the level up and down in the DPX Frequency display. The range of the Frequency Edge trigger is limited to ± ½(Acquisition bandwidth) if no resolution bandwidth is applied to the measurement, or ± ½ (Resolution bandwidth).

Consider the case of a phase-locked-loop switching between two output frequencies. The power may be constant through the frequency transitions, so there is nothing to cause a Power Level trigger. The Frequency Edge trigger, on the other hand, tracks the instantaneous frequency of the input signal, and compares it to the user-entered Frequency Level value. When the frequency trace crosses through this level, the instrument triggers. An example is shown in Figure 40.

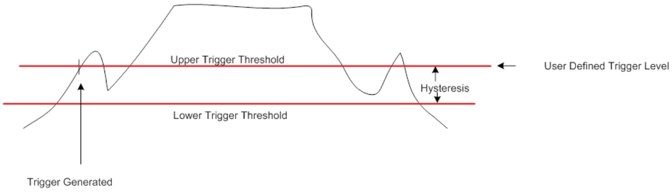
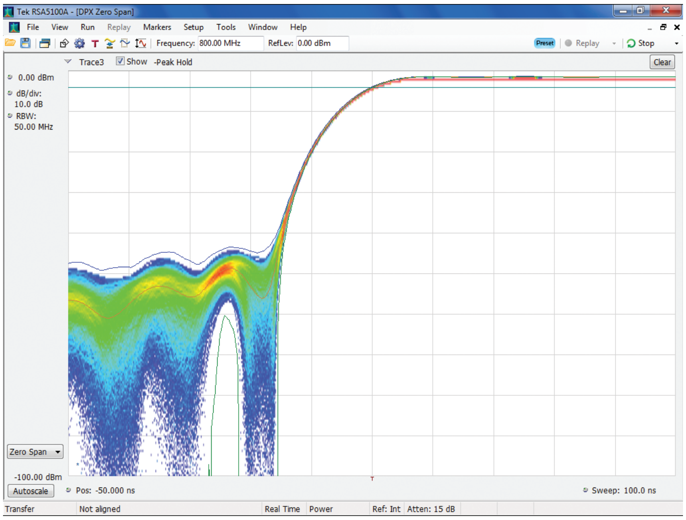


Figure 41. Hysteresis is applied to the frequency edge trigger to reduce the number of false triggers that result from noise signals. Starting from a user defined trigger level, hysteresis is subtracted from the user defined trigger level. The signal must pass through both the trigger level and the hysteresis level for a trigger to occur.

Another user setting for Frequency Edge triggering is Power Threshold, which is used to keep the instrument from triggering when the input amplitude is low, such as during pulse off periods. Signal power also measures low when the signal frequency is outside the bandwidth of the DPX measurement's RBW, or Time-Domain BW, filter. When the power is too low, frequency measurements are not valid, and can swing rapidly from one extreme to the other. Power Threshold should be set to a value well above the noise level of the input signal and somewhat lower than the signal's normal operating power.

Hysteresis is necessary for all trigger types, and is used to keep them from firing multiple times on a single edge due to noise causing multiple crossings of the threshold level. Hysteresis requires that a signal pass through two levels in order to generate a trigger, and the difference between the two levels is referred to as the hysteresis. See Figure 41 for a graphical representation of hysteresis applied to a rising frequency edge.

Hysteresis of the Frequency Edge trigger varies as the resolution bandwidth or time-domain measurement bandwidth is changed. It is set to 2% of the full trigger bandwidth, or 1 minor division on the screen when the scale is set to the full trigger bandwidth. Note that the DPX display's RBW value is always the same as the trigger's Time-Domain BW value. This is because of the sharing of hardware resources between DPX and triggers. Setting a wide RBW allows tracking the input signal over a wider range of frequencies, but it also results in a noisier trace. To keep the noise from degrading trigger performance, the hysteresis is automatically increased. If the input signal's frequency is varying over a range that is significantly smaller than the current RBW, it is possible for the trigger hysteresis to be larger than the signal's frequency range, which prevents triggering. As an aid for users, the hysteresis value is displayed as a readout in the Trigger control panel, near the Frequency Level control. When setting wide RBWs for DPX Frequency, users are advised to check this readout to make sure their signal's frequency crosses both edges of the hysteresis zone.



Frequency: 800.00 MHz

RefLev: 0.00 dBm

Trace3 ☑ Show -Peak Hold

0.00 dBm

dB/div: 10.0 dB

RBW: 50.00 MHz

-100.00 dBm

Pos: -50.000 ns

Sweep: 100.0 ns

Transfer | Not aligned | Real Time | Power | Ref: Int | Atten: 15 dB

Figure 42. At 100 ns sweep time, generating 801 points on the trace requires that incoming data be interpolated to an effective 8 GS/sec sample rate to produce a smooth display.

Fast Sweeps and Triggering

The fastest sweep speed for the DPX time-domain displays is 100 nsec. With a trace of 801 points, this requires an effective data rate of 8 GSamples/sec, much higher than the analyzer's actual sample rate (see Figure 42). Trace data is interpolated to the higher rate by writing the data samples into a FIFO, then reading them out slowly and interpolating them up to the required rate. This interpolation, in addition to mapping multiple acquisitions of trace data into each frame, populates the bitmap and insures there are enough points on even the fastest signal edges.

An important benefit of the high effective sampling rate after interpolation is trigger stability. The same circuitry that provides the internal triggering capability also implements the DPX functions; they operate on the same stream of data points from the A-to-D converter and decimating filters. The normal time resolution of the trigger is the same as the decimated sample interval. This is also the displayed trigger jitter for the DPX time-domain traces. But when the DPX time-domain display and the trigger source are set to the same signal type (Zero Span display and Power trigger, or Frequency display and Frequency Edge trigger), the trigger also benefits from DPX' interpolation, reducing the trigger resolution and displayed trigger jitter to one sample at the interpolated rate, which is 125 psec for the fastest sweep.

Figure 43. DPX spectrum display offers an intuitive live color view of signal transients changing over time in the frequency domain, giving you immediate confidence in the stability of your design, or instantly displaying a fault when it occurs.

Note that only the DPX time-domain displays receive the interpolated trigger. Other analyzer displays do not have access to this signal, so their trigger resolution is 1 decimated sample period.

Discover DPX

DPX technology in Tektronix' spectrum analyzers guarantees 100% Probability of Intercept for infrequent signal events as brief as 3.7 µsec. It also provides a true representation of multiple signals occupying the same frequency range. With the latest advances in DPX technology, you can now make signal density measurements, trigger on any visible signal, and span out to a multi-GHz view in the DPX Spectrum display.

More dramatic than any technical specification is how quickly you'll discover and resolve problems now that you can clearly see fleeting signals with the DPX Spectrum display. You don't need to know the size, shape or location of signals that might be present, or even that they exist. DPX simply shows them to you.

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Contact List Updated 10 February 2011

For Further Information

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