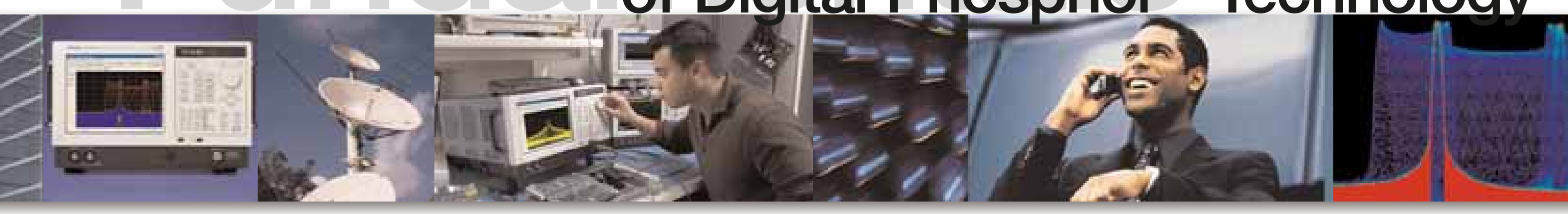
Fundamentals of Digital Phosphor™ Technology



in Real-Time Spectrum Analyzers

Tektronix
Enabling Innovation

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Digital Phosphor™ Technology in Real-Time Spectrum Analyzers: a Revolutionary Tool for Signal Discovery

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, standard in our next-generation RSA6100A Series Real-Time Spectrum Analyzers (RTSAs), reveals signal details that are completely missed by conventional spectrum analyzers and vector signal analyzers. The full-motion DPX™ Spectrum's live RF display shows signals never seen before, giving users instant insight and greatly accelerating discovery and diagnosis.

This primer describes the DPX™ Spectrum display and how it addresses situations involving brief, intermittent, complex and/or coincident signals. Also covered are the methods for achieving its key performance specifications:

– Detection and measurements on a signal as short as 24 microseconds

– 48,828 spectral transforms per second, compressed into a display that is even easier to read than a conventional spectrum trace

Digital Phosphor Display

The name "Digital Phosphor" derives from the phosphor coating on the inside of cathode ray tubes (CRTs) used as displays in televisions, computer monitors and older test equipment. When the phosphor is excited by an electron beam, it fluoresces, lighting up the path drawn by the stream of electrons.

Raster-scan displays (first CRT then LCD) replaced vector CRTs in many applications due to their smaller depth and lower power requirements, among other advantages. However, the combination of phosphor coatings and vector drawing in CRTs provided several valuable benefits.

Persistence: Phosphor continues to glow even after the electron beam has passed by. Generally, the fluorescence fades quickly enough that viewers don't perceive it lingering, but even a small amount of persistence will allow the human eye to detect events that would otherwise be too short to see.

Proportionality: The slower the electron beam passes through a point on the phosphor-coated screen, the brighter the resulting light. Brightness of a spot also increases as the beam hits it more frequently. Users intuitively know how to interpret this z-axis information: a bright section of the trace indicates a frequent event or slow beam motion, and a dim trace results from infrequent events or fast-moving beams. In the DPX display, both color and brightness provide z-axis emphasis.

Persistence and proportionality do not come naturally to instruments with LCDs (or even raster CRTs) and a digital signal path. Tektronix developed Digital Phosphor technology so the analog benefits of a vector CRT could be achieved, and even improved upon, in our industry-leading digital oscilloscopes and now in our real-time spectrum analyzers. Digital enhancements such as intensity grading, selectable color schemes and statistical traces communicate more information in less time.

Application: Finding low-level signals beneath a stronger signal

The RSA6100A Series DPX Spectrum display shows multiple signals sharing the same frequency at different times, not just the largest, smallest or average levels. An example to illustrate the advantages of the DPX display over traditional spectrum displays is a common WLAN communications interchange between a PC and a network access point (AP). With the laptop located one meter away from the analyzers used for this demonstration, and the AP at approximately thirty meters, the AP's signal is almost 30 dB below that of the laptop.

Each analyzer is equipped with an identical antenna and adjusted to show a detailed spectral display of the communications signals. The 802.11 WLAN signal is Complementary Code Keying (CCK), Time Division Duplexed (TDD) and transmitting with intermittent RF bursts at 2.46 GHz.

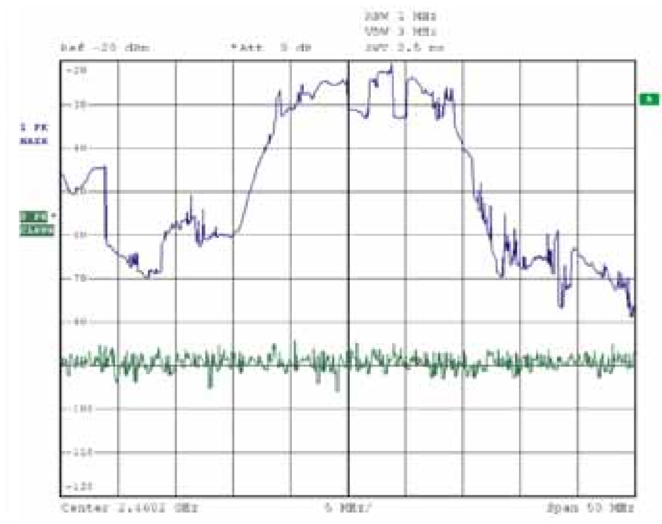
Two traces are configured in the swept spectrum analyzer's display because a spectrum trace formed by a single line of points across the screen cannot represent multiple amplitude values per frequency point. One trace is Max Hold, to show the stronger intermittent signal from the laptop. +Peak detection is selected for the other trace in an attempt to capture the weaker but more frequent AP signal (Fig 1).

After many sweeps, the conventional analyzer display shows a rough envelope of the nearby laptop signal. However, the trace has several rectangular notches that don't represent the true WLAN signal. These dropouts show up in periods of the sweep that don't happen to coincide with the laptop's transmit times. ("Probability of Intercept" will be addressed in more detail later in this paper.) If the signal remains active long enough, the notches will fill in and the trace will assume a shape more closely approximating the real signal.

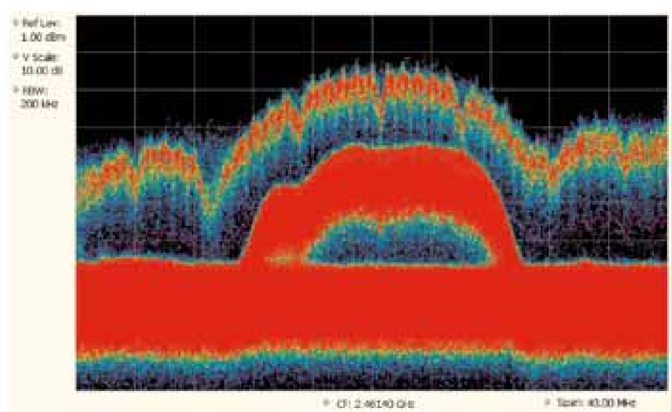
The peak-detected trace, containing data from only the most-recent sweep, was unable to capture the lower-power AP signal. The bursts are very brief, so the likelihood of seeing one in any particular sweep is small.

The DPX display (Fig 2) shows a very different picture of the communications interchange. Since it is a bitmap image instead of a line trace, you can distinguish many different signals occurring at the same time and/or different versions of the same signal varying over time. The live RF appearance lets you see the signals varying over time.

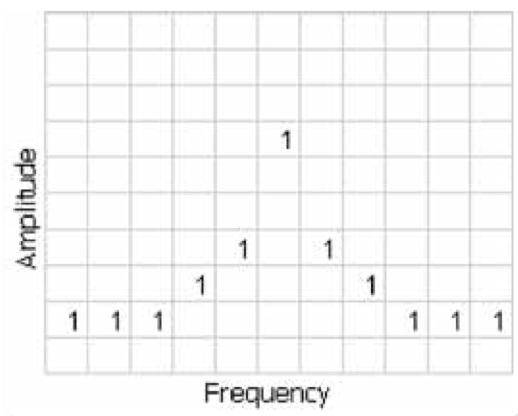
The heavy band running straight across the lower third of the graph is the noise background when neither the laptop nor the AP is transmitting. The red energy lump in the middle of the graph is the ON shape of the AP signal. Finally, the more delicate spectrum above the others is the laptop transmissions. 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 picture was taken.

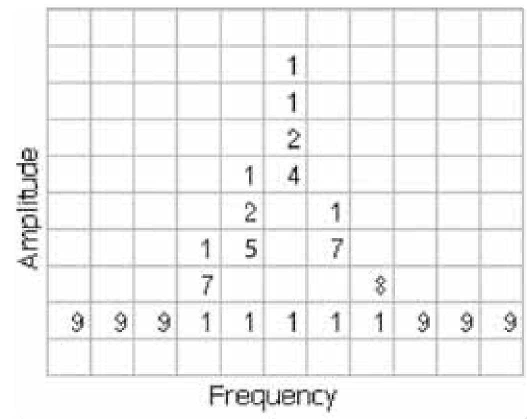


▶ **Figure 1.** *Max Hold and Normal traces on a swept spectrum analyzer, both using +Peak detection. The Max Hold trace shows the laptop's stronger signal, but neither trace shows the lower-power access point transmissions.*



▶ **Figure 2.** *The RSA6100A Series' DPX Spectrum display shows the laptop transmissions, access point signal and background noise, all in its live-motion bitmap trace.*





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

Though these signals have duty factors and repetition rates too low for conventional analyzers, they are well within the basic capabilities of DPX technology. Variable persistence, adjustable intensity and other advanced resources allow the RSA6100A Series to handle signals even more elusive than these.

The DPX Display Engine

Compressing 1465 spectral measurements into one screen update every 33 milliseconds is an oversimplified description of the role DPX technology performs in the RSA6100A Series. 48,828 acquisitions are taken and transformed into spectrums every second. As we shall see in a later section of this brief, this high transform rate is the key to detecting infrequent events, but it is far too fast for the liquid-crystal display to keep up with, and it is well beyond what human eyes can perceive. So the incoming spectrums are written into a bitmap database at full speed then transferred to the screen at a viewable 30-Hz rate.

Picture the bitmap database as a dense grid created by dividing a spectrum graph into rows representing trace amplitude values and columns for points on the frequency axis. Each cell in this grid contains the count of how many times it was hit by an incoming spectrum. Tracking these counts is how Digital Phosphor implements proportionality, so you can visually distinguish rare transients from normal signals and background noise.

The actual 3-D database in an RSA6100A Series Real-Time Spectrum Analyzer contains 501 columns and 201 rows, but we will use an 11X10 matrix to illustrate the concept. The picture on the left in Figure 3 shows what the database cells might contain after a single spectrum is mapped into it. Blank cells contain the value zero, meaning that no points from a spectrum have fallen into them yet.

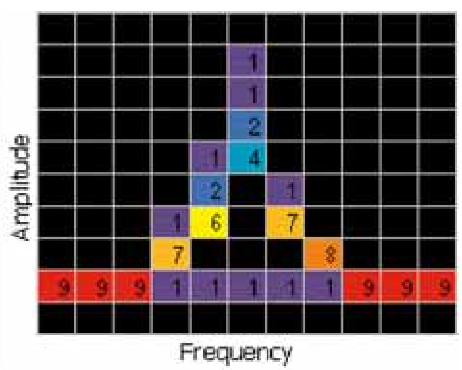
The grid on the right shows values that our simplified database might contain after an additional eight spectral transforms have been performed and their results stored in the cells. One of the nine spectrums happened to be computed at a time during which the signal was absent, as you can see by the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

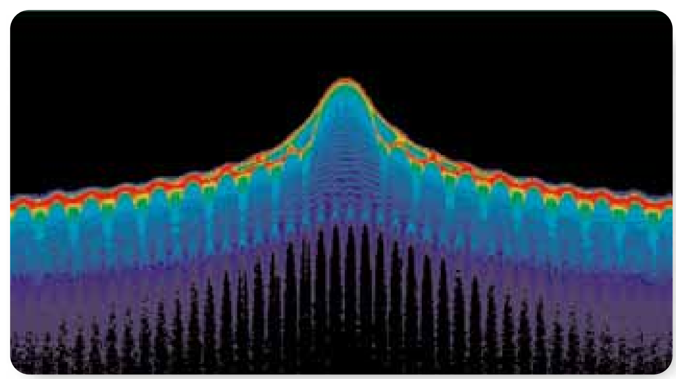
When we map the Number of Occurrences values to a color scale, data turns into information. The table found in Figure 4 shows the color mapping algorithm that will be used for this example. Warmer colors (red, orange, yellow) indicate more occurrences. Other intensity-grading schemes can also be used.

The picture below left (Fig 5) is the result of coloring the database cells according to how many times they were written into by the nine spectrums. Displaying these colored cells, one per pixel on the screen, creates the spectacular DPX displays.

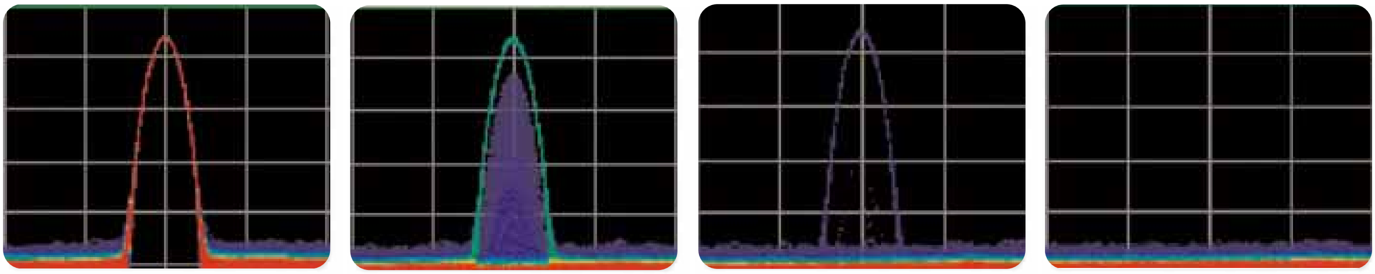
Number of Occurrences	Color
0	black
1	blue
2	light blue
3	cyan
4	green blue
5	green
6	yellow
7	orange
8	red orange
9	red

▶ **Figure 4.** *Example Color-mapping Algorithm*





▶ **Figure 5.** *Color-coded low-resolution example (left), and a real DPX display (right)*



▶ **Figure 6.** *With variables persistence, a brief CW signal captured by DPX remains in the display for an adjustable period of time before fading away.*

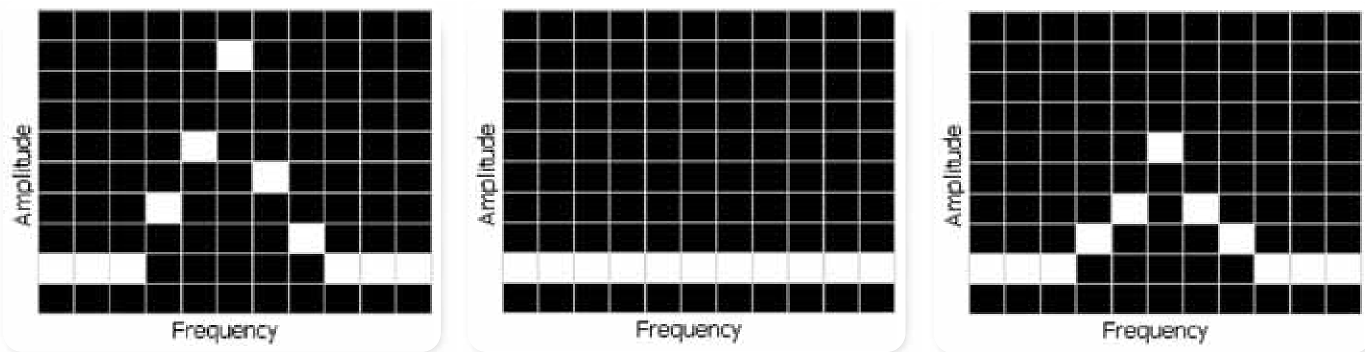
Persistence

In the instrument, 48,000+ spectrums enter the database each second. At the end of each frame of 1400+ input spectrums (about 30 times per second), the bitmap database is transferred out for additional processing before being displayed, and data from a new frame starts filling the bitmap.

To implement persistence, the DPX engine can, rather than clearing the bitmap database counts to zero at the start of each new frame, keep the existing counts and add to them as new spectrums arrive. Maintaining the full count values across frames is "infinite persistence". If only a fraction of each count is carried over to the next frame, it is called "variable persistence". Adjusting the fraction changes the length of time it takes for a signal event to decay from the database, and thus fade from the display.

Imagine a signal that popped up only once during the time DPX was running. Further, assume that it was present for all 1465 of the spectrum updates in a frame and that the Variable Persistence Factor causes 25% attenuation after each frame. The cells it affected would start out with a value of 1465 and be displayed at full force. One frame later, the Number of Occurrences values become 1099. After the next frame, they are 824, then smaller and smaller until they are so dim as to be invisible. On the screen, you would initially see a bright trace with a spike at the signal frequency. The part of the trace where the signal occurred fades away. During this time, the pixels start to brighten at the noise level below the fading signal. In the end, there is only a baseline trace in the display (Fig 6).

Persistence is an extremely valuable troubleshooting aid, delivering all the benefits of MaxHold and more. To find out if there is an intermittent signal or occasional shift in frequency or amplitude, you can turn on Infinite Persistence and let the RSA6100A Series baby-sit. When you return, you will see not only the highest level for each frequency point, but also the lowest levels and any points in between. Once the presence of transient behavior or intruding signals has been revealed, you can characterize the problem in detail with Variable Persistence.



+Peak Detection *- Peak Detection* *Average Detection*

▶ **Figure 7.** *Detected traces for our little example*

Statistical Line Traces

A colorful bitmap is DPX Spectrum's signature trace, but DPX also produces statistical line traces. The database contents are queried for the highest, lowest and average amplitude values recorded in each frequency column. The three resulting trace detections are +Peak, -Peak and Average (Fig 7).

The +Peak and -Peak traces show signal maxima and minima instantly and clearly. Average detection finds the mean level for the signal at each frequency point. All these traces can be saved and restored for use as reference traces.

Just like regular spectrum traces, DPX line traces can be accumulated over ongoing acquisitions to yield MaxHold, MinHold and Average trace functions. Using Hold on the DPX +Peak trace is almost exactly the same as the Max Hold trace on a typical spectrum analyzer, with the important difference that the DPX trace's update rate (48k/second, just like the DPX bitmap) is three orders of magnitude faster.

Super-Fast Spectral Updates

You just read about the DPX display engine compressing and processing more than 48,000 incoming spectrums each second. So how do all those spectrums get generated? To understand this, we need to briefly review the architecture of a Real-Time Spectrum Analyzer.

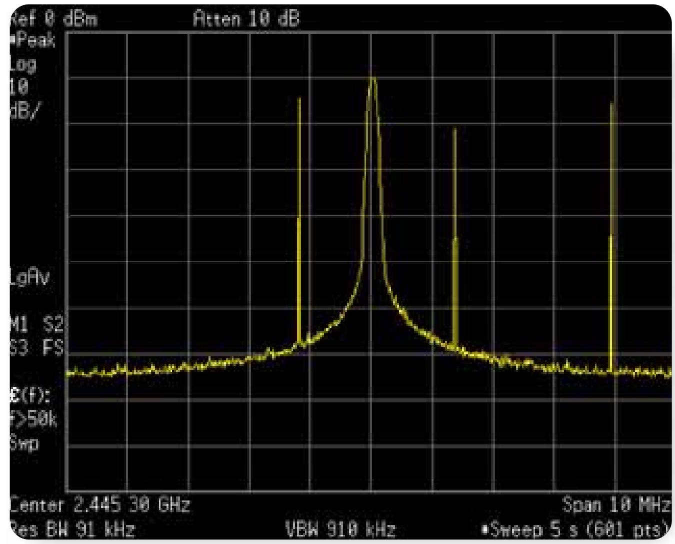
Like any other type of spectrum analyzer, an RTSA has an RF input section for analog signal conditioning (gain/attenuation, down-conversion, mixing, filtering…). Next, an analog-to-digital conversion stage produces a stream of amplitude values, one for each sample period. This A/D output is fed directly to a hardware-based digital downconverter that performs the final frequency conversion to baseband. The result is a real-time corrected data record containing an I and Q value pair for each time sample. Most RTSA measurements and trace displays, including the regular spectrum view, are post-processed from this IQ-vs-Time data record. But not DPX.

The DPX Transform Engine

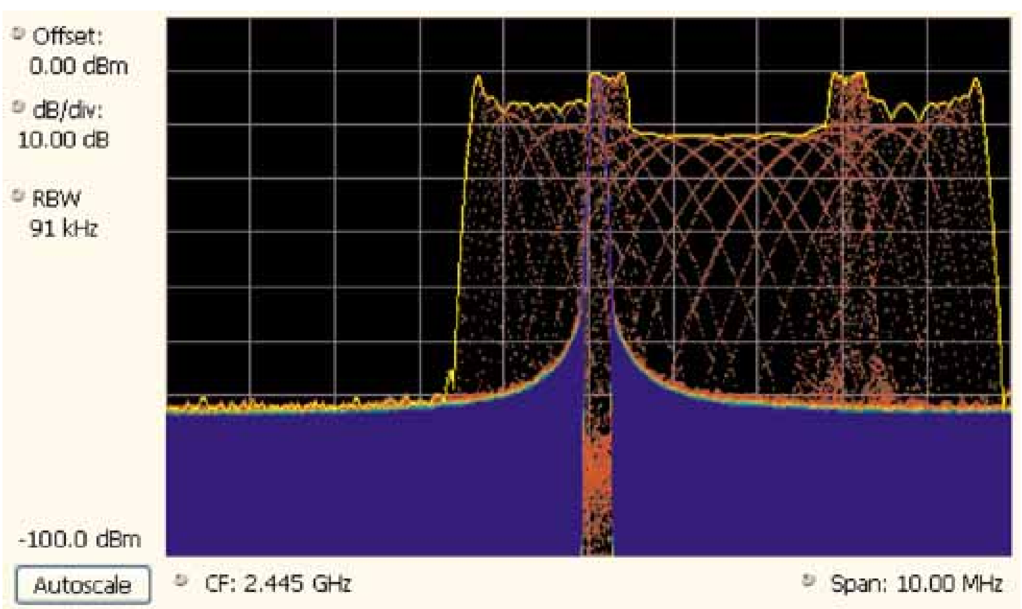
In parallel with the software batch processing used for most measurements, and using the same stream of incoming IQ data, there is a hardware-based computation engine devoted to continuous, real-time signal processing. This subsystem supports time-critical functions like power level triggering, frequency mask triggering and others. It also performs Discrete Fourier Transforms (DFTs) fast enough to produce the 48,000+ spectrums per second used by the DPX display system.

Application: Guaranteed detection of short, infrequent signals

Our challenge signal is a CW sinusoid at 2.4453 GHz. 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%. Let's see how well we can characterize this signal using a swept-tuned spectrum analyzer and an RSA6100A Series Real-Time Spectrum Analyzer with DPX.



▶ **Figure 8.** *Swept analyzer after 5 seconds: MaxHold trace*



▶ **Figure 9.** *DPX Spectrum display after 5 seconds Bitmap color mapping is "Spectral", to emphasize infrequent signals with hot colors. MaxHold trace is yellow.*

A swept analyzer is set up for a 5-second sweep of its MaxHold trace. It shows that there is something occurring around the signal (Fig 8). 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.

After a 5-second period, a DPX display using both the bitmap and a +PeakHold trace shows a lot more information about the transient (Fig 9).

After 120 seconds (four sweeps of 30 seconds), additional clues are visible in the swept analyzer's display (Fig 10).

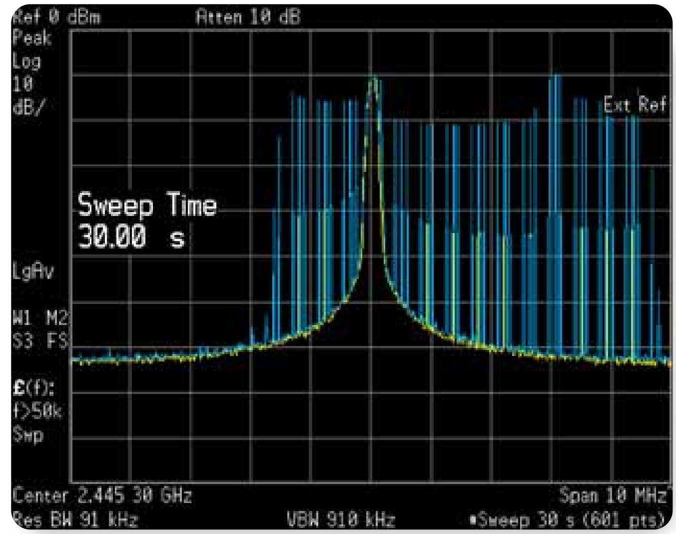
The DPX Spectrum display, after only 20 seconds, shows a much more informative picture (Fig 11). It is obvious at first glance that the CW signal is hopping up to a frequency about 3 MHz higher than its starting point, but overshooting by 1.5 MHz, then undershooting a little, and finally settling. Then it hops back to 2.4453 GHz, again with some frequency overshoot and settling.

Probability of Intercept

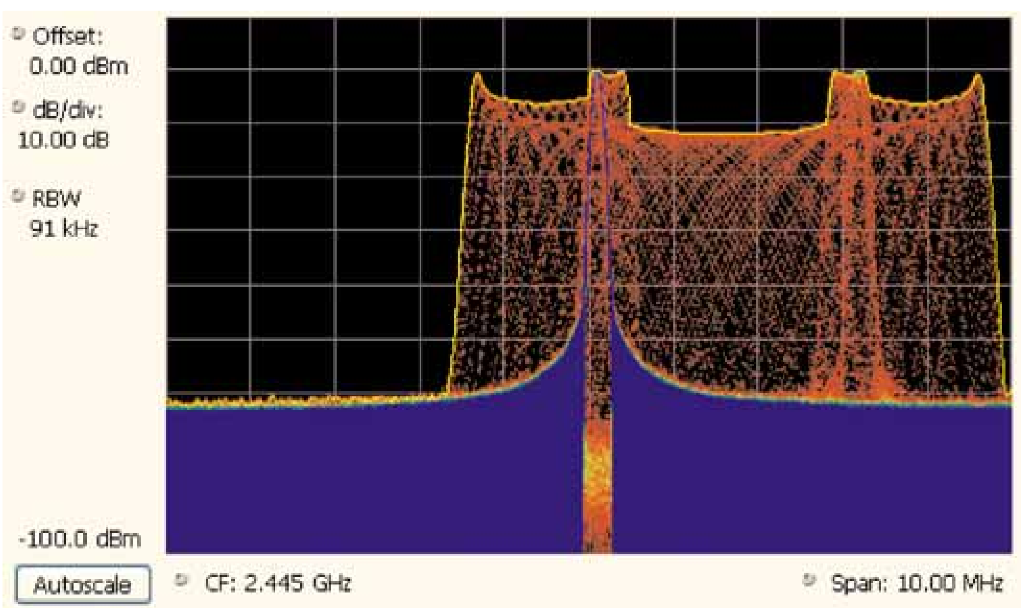
How likely are you to see the aberrant signal on your spectrum analyzer? To find out, we will compare the Probability of Intercept (POI) for various analyzer classes.

The main reason that swept-tuned and step-tuned spectrum analyzers can't provide 100% POI for a signal that isn't continuously present is that they spend only a short period of time tuned to each small portion 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 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 is typically better than a swept analyzer's, ranging from very small to moderate, depending on a combination of factors including span, number of FFT points, acquisition time and sweep rate.



▶ **Figure 10.** *Swept analyzer MaxHold trace after 120 seconds*



▶ **Figure 11.** *DPX bitmap and MaxHold trace after 20 seconds*

RTSAs, on the other hand, capture data across all frequencies within their real-time span (up to 110 MHz for the RSA6100A Series) during every acquisition. With Tektronix' exclusive Frequency Mask 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 RTSA has a POI similar to other FFT-based analyzers, with gaps between each acquisition.

Adding DPX technology brings 100% POI to free run mode for any signal at least 24 microseconds long and within the real-time bandwidth. The RSA6100A Series owes this performance to its 48K spectrum transforms-per-second rate. The faster the spectrum updates, the shorter the time between acquisitions and the greater the probability that any signal will be detected.

Discover DPX

DPX technology in Tektronix RSA6100A Series Real-Time Spectrum Analyzers guarantees 100% Probability of Intercept, even for infrequent signal events as short as 24 μsec. It also provides a true representation of multiple signals occupying the same frequency range.

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.

Getting the most out of the DPX Spectrum Display

Here are a few tips on setting up the DPX Spectrum display and for using it with other functions in the RSA6100A Series Real-Time Spectrum Analyzer.

Adjustments for the Bitmap Display

The DPX Spectrum display has a handful of controls for tuning the bitmap to emphasize specific signal types, and to get the particular look you like.

Persistence

With Persistence turned OFF, the DPX bitmap clears the display and repaints it with new data about 30 times per second.

Infinite Persistence allows the data to keep building up until you press Clear or start a new cycle with the Run button. In this setting, no data is erased when new data is added, so all signals are maintained in the view.

Variable Persistence allows you to control how fast or slow the displayed points fade from the screen. The persistence helps emphasize short and/or rare events, while the fading away of older points keeps them from obscuring the arrival of interesting new data.

Intensity

Though implemented digitally, this feels like a good old analog CRT control. Increasing the Intensity brightens the points, allowing you to see infrequent events that might have been somewhat dim. Or, in the case of a continuous signal surrounded by noise, you can de-emphasize the noise by turning down the Intensity.

Color Palettes

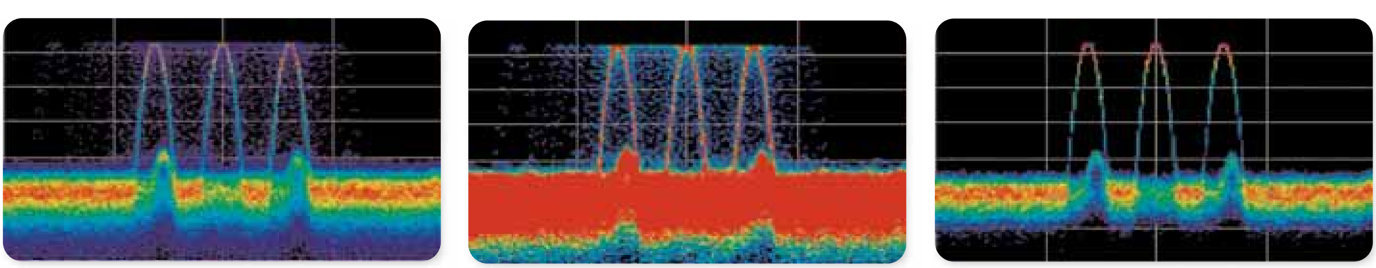
Part of what makes the DPX bitmap display so intuitive is its intensity grading. A user-selectable color palette is applied to the data, with high-intensity color and/or brightness mapped onto high-count grid locations and cooler, dimmer colors indicating low-count points. There are a couple of full-color palettes available (Temperature and Spectral), many different monochrome selections and even a binary scheme that shows unambiguously which points have been hit and which have not.

Color Scale

Max and Min adjusts how the “Percent of Occurrences” values from the pixel database are mapped onto the color scale. By default, any cells with zero occurrences are painted with the bottom color in the scale (black) and cells containing the highest possible count are assigned the color at the very top of the scale (Fig 12, left).

Reducing the Max setting allows lower-than-maximum count values to reach the top of the color scale. This lets you use the full range of colors to focus in on middle- or lower-occurrence events (Fig 12, center).

Similarly, increasing the Min setting means that infrequent events will be black, just like the background of points that received no events. This is not a common setting to use, but lets you screen out rarely-occurring signals that are not important to your current task (Fig 12, right).



Max = 100, Min = 0 *Max < 100* *Min > 0*

▶ **Figure 12.** *Effects of Color Scale Max and Min Adjustments on the DPX Bitmap Display*

Interaction with other RTSA Functions

DPX Spectrum is a special display; it follows some of the RSA6100A Series' general display conventions but not all of them. DPX Spectrum uses the normal spectrum-analyzer controls, but there are a few RTSA functions that don't apply to DPX.

RBW

The DPX Spectrum display has its own RBW control which is independent of the RBW settings for other displays and measurements. If an RBW in the normal valid range is selected, but the actual acquisition bandwidth decreases or increases such that the selected value can't be realized, the RBW computation temporarily adjusts to the closest value that it can achieve. A message containing this temporary RBW value is displayed in the graph.

Span

The Span of the DPX Spectrum display ranges from 100 Hz to 110 MHz (to 40 MHz for instruments without the 110 MHz option). DPX always uses real-time acquisitions; it does not step across multiple frequency spans to construct a "swept" display.

Markers

For DPX statistical line traces, markers are no different than for line traces in other displays. What might surprise you is that markers can also be assigned to the bitmap trace. DPX calculates an average trace even when it is not visible in the display, and any markers assigned to the DPX bitmap trace are positioned on the average trace's points.

Frequency Mask Trigger

DPX Spectrum and Frequency Mask Trigger (FMT) share some of the same hardware for fast spectrum transforms. For this reason, they cannot both operate at the same time in the instrument.

Frequency Mask Trigger has the higher priority, so if both functions are requested by the user, FMT will operate normally, but the DPX Spectrum graph will be empty except for a message explaining that FMT is using the shared hardware resources.

Analysis Time

Most measurements in the RSA6100A Series Real-Time Spectrum Analyzers are computed over a portion of the acquisition data record called the "Analysis Time". These are post-acquisition processes, with the ability to operate on recalled data files and under different settings.

DPX Spectrum is a fast, continuous process rather than a post-processing measurement. Analysis Time does not apply to it.

Power Level Triggering

DPX just runs. It runs fast; it runs continuously whenever the Run button is lit, paying no attention to triggers. Even when other measurements are using triggered acquisitions, DPX free runs.

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