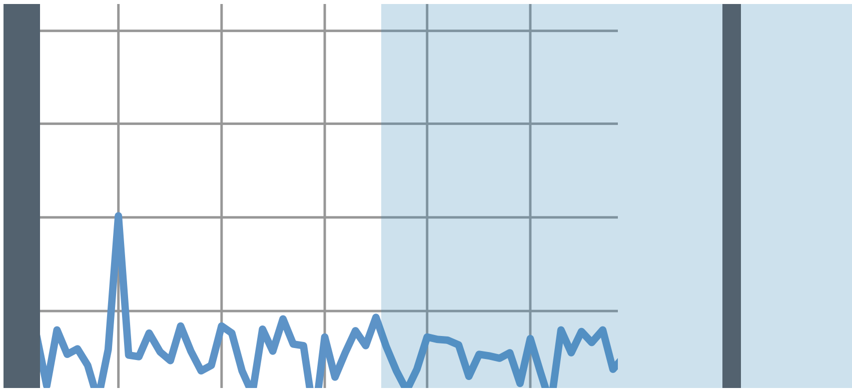

# Fast, Low Level Spurious Search with Tektronix Real-Time Signal Analyzers

Application Note

Historically, long test times have been required to perform low-level spur searches on high performance RF and microwave systems. In this application note, learn how the unique wideband architecture of the Tektronix Real-Time Signal Analyzers provides a breakthrough approach for this critical test, resulting in faster time to results and a significantly reduced test budget.

## Introduction

A common bottleneck in the design and deployment of high performance RF and microwave systems such as radars and ground or space-based communications links is the test time required to perform low-level spur searches. These tests typically require spectrum analyzer measurements with low measurement noise floors using low Resolution Bandwidth settings, which inherently make test times long. The root of the problem is that traditional spectrum analyzers sweep times increase proportional to the inverse of the square of the Resolution Bandwidth Filter used. Modern Spectrum Analyzers with Fourier analysis based on digital signal processing (DSP) ameliorate the problem somewhat, but still suffer from long FFT computation times and the large number of relatively narrow (typically <10 MHz) acquisitions needed to cover the several GHz of span required in many spur searches.

Testing over various environmental conditions exacerbates the problem, requiring hundreds of hours to fully characterize the spurious performance of the system. Using Tektronix Real-Time Signal Analyzers with their unique wide band architecture can enable a breakthrough in the time needed to perform exhaustive spur searches. The Tektronix RSA is based on an FFT-analyzer architecture that processes up to 110 MHz of bandwidth per step, and then computes the FFT for each step across a 20 GHz bandwidth. FFT processing of a wide acquisition results in a significantly faster way to cover wide spans with narrow RBWs. Tektronix Real-Time Signal Analyzers also include DPX® and Swept DPX modes that allow the discovery of transient spurious events in addition to the conventional steady-state spurs. A case study is presented that shows how the test time saved using the Tektronix RSA over other spectrum analyzers can result in faster time to results and a significantly reduced test budget.

Tektronix®

# The Test Challenge Presented by Spurs

## Measuring Low Levels

Spurious testing is frequently the bottleneck in test time for high performance RF and microwave systems. RF and microwave transmitters often require exhaustive spur searches to ensure they are not causing potential interfering signals or radiating unintended signals outside of their designated signal parameters. Examples of this include radar systems that require signal security where spurious emissions can give away a signal's spectral and spatial location and cellular base station transmitters, where spurious signals can interfere with other licensed users of the spectrum.

Spurious requirements are often expressed in terms of spectral emissions masks or as direct testing specifications that often call for measurements at extremely low levels. Spectrum analyzers must incorporate low noise preamplifiers as well as very narrow resolution bandwidths (RBW) in order to the reach low level noise floors required to adequately test spurious requirements of modern devices and systems. Other techniques are also used to improve the measured noise floor of a spectrum analyzer. These include averaging and various DSP techniques that measure and subtract the inherent noise floor of the analyzer. Typically, in order to achieve a very low noise floor, the spectrum analyzer user must use a combination of techniques in addition to very low RBW settings. The sweep time required to adequately measure spurs at a level of a -120 dBm can range from 30 minutes to over 8 hours for a 20 GHz span.

Low level spur tests are often repeated many times while changing the environmental conditions of the device under test. Satellite components can undergo large temperature changes while operating. Cellular base stations endure wide temperature and humidity changes during operation. For these and other devices, the testing needs to simulate similar temperature, humidity and pressure changes that the device will encounter over its operational life. This presents a large number of spur tests, each one with the same noise floor requiring the very low RBW to measure. Potentially, many spur tests could be required to complete the environmental characterization, which can range in the 100's of hours of test time for high performance devices and systems.

### The Need for Narrow Resolution Bandwidth (RBW)

Noise in electronic systems is caused by several processes including the thermally generated random motion of molecules (kTB), the granular nature of electrical charges (shot noise), the process by which junctions break down (avalanche noise) and others. In most cases, the power spectral density of noise can be approximated as a uniform or flat distribution. This is called white noise. The uniform distribution in white noise means that noise power is proportional to bandwidth. Spur searches usually involve measurements where sinusoidal signals and noise appear together. Reducing the measurement bandwidth (RBW) reduces the amount of measured noise power but not the power in any sinusoidal components within the pass-band of the filter. A small RBW enables the spectrum analyzer to expose the sinusoidal signal components that would otherwise be buried in noise.

Consider a spurious test requirement calling for the measurement of all spurious signals with levels above -120 dBm. The spectrum analyzer must be able to distinguish the spurious signal from the surrounding noise, typically requiring at least 15 dB of margin over the analyzer's average noise level. The spectrum analyzer must therefore provide an average noise level of -135 dBm or better. For a high performance spectrum analyzer with a typical displayed average noise level (DANL) of -155 dBm in a 1 Hz BW at 20 GHz, this requires a RBW of 100 Hz or lower as shown in the equation below.

The required RBW can be computed from the spectrum analyzer's DANL and the required noise margin

$$\boldsymbol{W = 10^{\left[\frac{L_S(dBm) - N_m(dB) - DANL\,(dBm/Hz)}{10}\right]}},$$

where $L_s$ is the minimum spur level required in dBm, *DANL* is the analyzer's displayed average noise level expressed as dBm in a 1 Hz BW and $N_m$ is the noise margin in dB.

Using our example above,

$$\boldsymbol{RBW = 10^{\left[\frac{-120-15-(-155)}{10}\right]} = 10^{\left[\frac{20}{10}\right]} = 100\ Hz}.$$

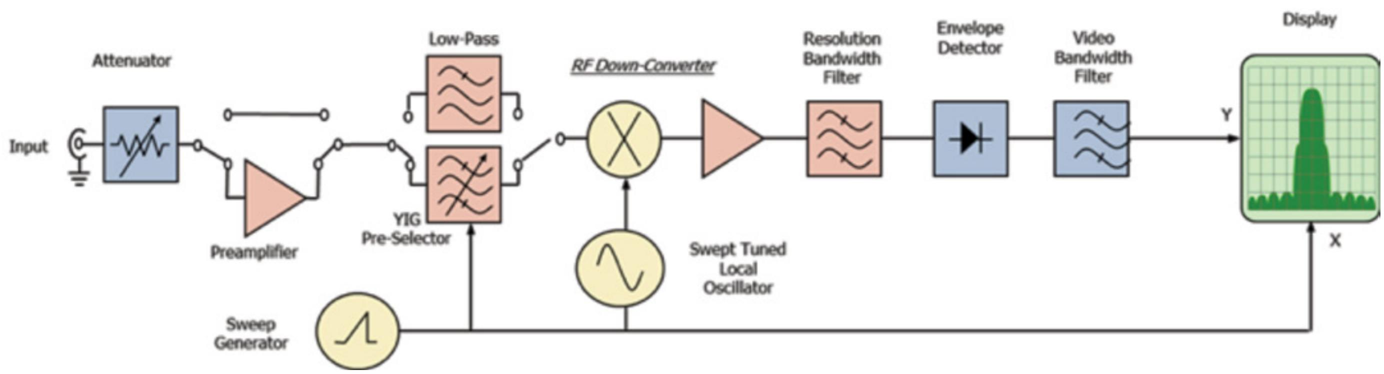


**Figure 1.** Block diagram of a traditional swept-tuned spectrum analyzer.

### Noise Floor Subtraction

Another way to reduce the measurement noise floor of a spectrum analyzer is to measure its noise floor with the input terminated and then to subtract it from subsequent measurements. This method, while effective at reducing the measurement noise floor and aiding in the detection of spurs that are near noise, increases measurement uncertainty and the variability of the measurement results. Reducing the RBW is the usual preferred way to measure low level spurs while minimizing measurement variability and maintaining accuracy specifications.

## Spectrum Analyzer Architectures

### Traditional Swept Spectrum Analyzers

Traditional instruments are well suited to perform spurious measurements. The primary reason for this is that traditional spectrum analyzers use a narrow bandwidth IF. The LO is swept across the frequency span of interest, effectively sweeping the narrow IF filter across the span of interest. The benefit of this architecture is the dynamic range and sensitivity of the instrument can be very good, with the drawback of performing this measurement very slowly. It is a well-established concept that the sweep time of a swept spectrum analyzer is inversely related to the square of the resolution bandwidth setting. As a rough approximation, every 3 dB improvement gained in the noise floor of the spectrum analyzer results in a 4X degradation in sweep speed. An example of a typical high performance spectrum analyzer would require over 3000 seconds (50 minutes) for a 20 GHz sweep to measure a -135 dBm spur at 10 GHz.

Figure 1 illustrates the signal path of a traditional spectrum analyzer. The signal often is amplified in a preamplifier and then down converted and filtered in the intermediate frequency (IF) portion of the instrument. The narrow band IF signal is then detected and converted to decibels, producing the traditional display that expresses the level of the various spectrum components in dBm versus frequency.

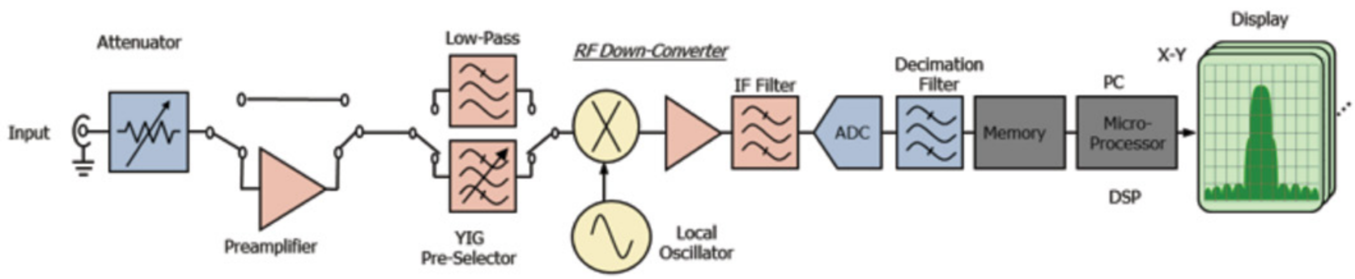


**Figure 2.** Block diagram of a modern spectrum analyzer with DSP.

Modern spectrum analyzers have incorporated analog-to-digital conversion (ADC) and digital signal processing (DSP) into their architecture as shown in Figure 2. A swept local oscillator is used to convert the input signal into a narrow-band IF section which filters and amplifies the signal. Instead of a level detector, modern spectrum analyzers use an analog-to-digital (ADC) converter to create a numeric representation of the signal under test. Digital Signal Processing techniques including filtering and FFTs are then used to compute the spectrum.

Many modern spectrum analyzers using the kind of architecture shown in Figure 2 have several modes of operation. The normal mode, which is optimized for highest dynamic range, uses a relatively narrow IF filter (sometimes called an IF pre-filter) to limit the bandwidth of signals that reach the ADC and applies DSP to generate the appropriate RBW filter shape. This approach optimizes dynamic range but still suffers from the slow sweep rates required by narrow filters. Fast Fourier Transform (FFT) techniques are often used to synthesize the narrowest RBWs, giving the modern analyzers a significant boost in speed over their purely analog predecessors when RBWs of less than 1 KHz or so are needed. An alternate mode, optimized for speed, uses a relatively wide IF filter (Typically in the order of 10 MHz to 25 MHz) and FFT processing to generate fairly fast spectrum displays. The analyzer's spurious performance is often degraded in this mode, making it a less than ideal choice for very low spurious measurements.

Modern Spectrum Analyzers often incorporate Vector Signal Analyzer (VSA) functionality in order to make measurements in digitally modulated signals. This mode, optimized for the flat amplitude and linear phase response needed to accurately measure digital modulation, uses wide IF filters (Up to 160 MHz BW at the time of this writing) and DSP to make vector (magnitude and phase) measurements. Although FFT analysis can be performed in this mode, it is generally unsuited for spurious measurements because YIG tune pre-selector needs to be bypassed to provide the signal fidelity required for modulation analysis. Bypassing the YIG filter introduces a large number of internally generated spurs including mixer images and harmonic responses.

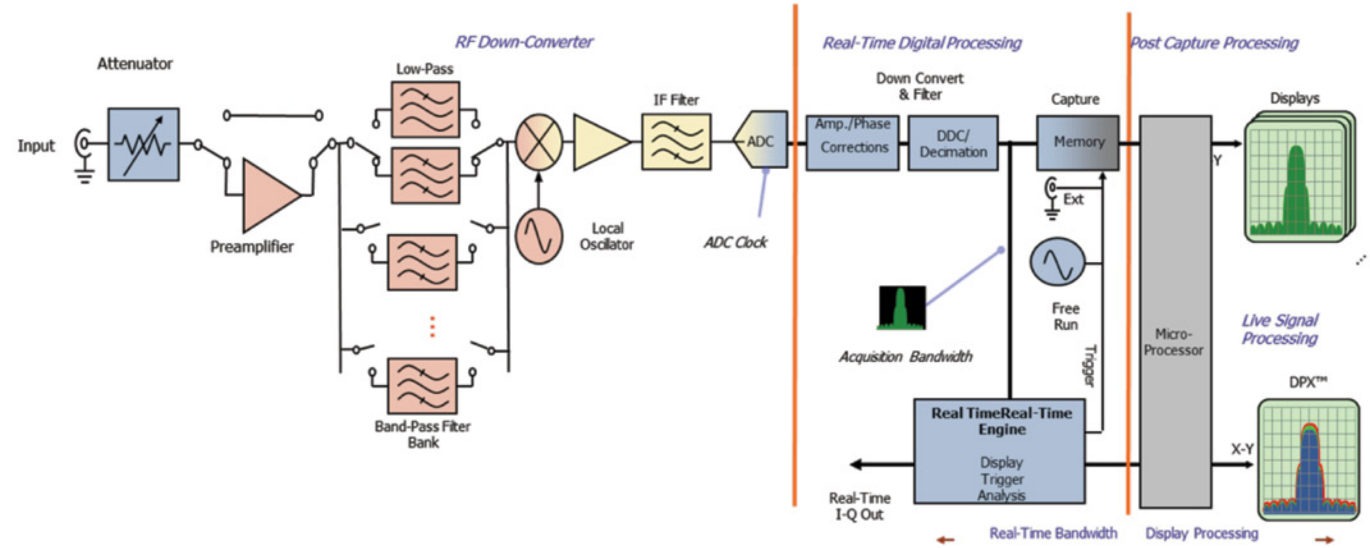


**Figure 3.** Block diagram of a Real-Time Signal Analyzer (RSA).

### Real-Time Signal Analyzers

Figure 3 shows a block diagram of a Real-Time Signal Analyzer (RSA). Like its predecessors, the RSA passes the signal through an optional preamplifier to improve sensitivity. Rather than using a tunable YIG filter for image rejection, the RSA uses a bank of switchable band pass filters with well-defined pass band and rejection characteristics. Not only do these filters provide image rejection but their pass-band responses are designed to be flat and stable enough to allow for calibrated vector measurements with specified magnitude and phase response over wide bandwidths (up to 110 MHz in the RSA6000 Series).

After the switched filter bank, the image-free signal is down-converted to a wide-band IF section and then digitized. The time domain samples are then continuously digitally converted to a baseband data stream composed of a sequence of I (in phase) and Q (quadrature) samples. This digital down-conversion is done in real-time allowing no gaps in the time record. The same IQ samples can also be simultaneously stored in memory for subsequent analysis using batch mode digital signal processing (DSP).

### Wide Band Acquisitions

The basic Real-Time Signal Analyzer acquisition engine digitizes a wide band of frequency (up to 110 MHz in the RSA6000 series). All signals contained within the acquisition bandwidth are included. High dynamic range analog-to-digital converters (ADC) and proprietary signal processing techniques are used to perform the analog-to-digital conversion without the introduction of ADC related spurs.

### Covering Wide Spans with Narrow RBWs

Consider the 20 GHz spur sweep presented in the introduction. The spectrum analyzer is required to sweep across 20 GHz of spectrum with a 100 Hz resolution bandwidth. The sweep speed is restricted by the amount of time signals must be inside the RBW for an accurate measurement. The RSA does not use narrow filters and does not sweep. All acquisitions are done in a wide band (up to 110 MHz in the RSA6000 Series). Fourier transforms are performed in DSP. Large memory size and the application of modern high speed DSP engines allow long FFT frames and narrow RBWs to be processed orders of magnitude faster than with the use of actual filters. The center frequency is stepped with a step size equivalent to the acquisition bandwidth allowing very wide spans to be quickly covered.

### Real-Time Processing

The Real-Time processing engine is a combination of hardware and software optimized to perform computations at a rate that keeps up with the incoming stream of IQ data. Discrete Fourier Transforms (DFTs) are sequentially performed on segments of the IQ record generating a mathematical representation of frequency occupancy over time. Real-Time Signal Analyzers generate spectrum data at rates that are much too fast for the human senses. Visual data compression techniques must be used in order to generate a meaningful display. Digital Phosphor Technology or DPX® Spectrum is one such technique that provides an intuitive "live" view of complex and dynamic spectrum activity.

The Real-Time processing engine can also be used to generate a trigger signal based on specific occurrences within the input signal. These occurrences can be frequency domain patterns such as transient spurs, time domain events or modulation events. The trigger signal can be used to store specific segments of the IQ time record for further analysis using batch mode DSP.

In addition to the traditional spectrum analysis, Real-Time Signal Analyzers have the ability to perform multiple time-domain, frequency-domain, modulation-domain and code-domain measurements on RF and microwave signals and to display these measurements in a way that is correlated in time, in frequency and as a function of modulation events.

### Real-Time Corrections

One of the advantages of the RSA is the high speed Real-Time processing engine can be used to apply calibrations and corrections to the incoming signal. Compensation for the frequency response of the RF and IF filters as well and calibrations for level accuracy are performed in real time before the samples are placed into memory. This greatly speeds up the measurement process and allows for real time and batch mode measurements to be made on the same corrected data.

### DPX® and Swept DPX

DPX technology is designed to identify and measure transients. DPX mode can continuously observe a wide pass-band (110 MHz in the RSA6000 Series) in real time. Spectrum events lasting as little as a few microseconds can be detected, measured and displayed with 100% probability. Swept DPX sequentially steps the center frequency, dwelling for a time at each step. This allows up to 20 GHz of spectrum to be observed for rare transient events. Although this method does not achieve 100% probability of detection for single shot events, the probability of detection for rare events is greatly enhanced over conventional spectrum analysis. Swept DPX is a very useful tool in hunting for spurs that come and go. This kind of spurious has become more prevalent in modern equipment that combines digital processing in the same enclosure as RF signal processing.

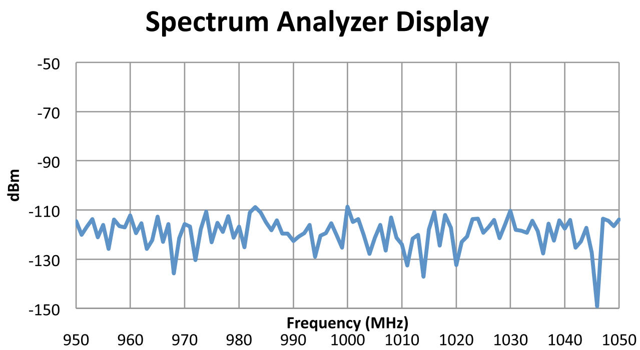


**Figure 4.** Spectrum Analyzer Trace with signal near noise
(1GHz signal = -110 dBm, DANL=-150 dBm/Hz, RBW=1000 Hz).

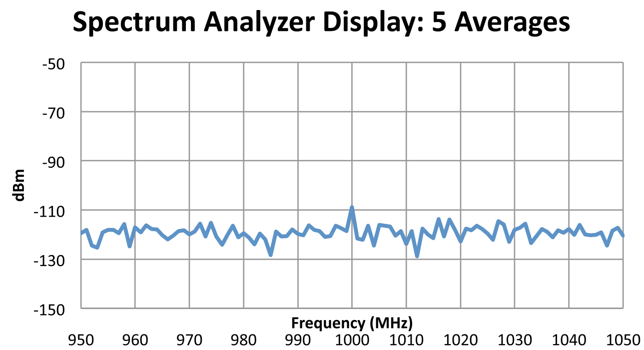


**Figure 5.** Spectrum Analyzer Trace with signal near noise
(1 GHz Signal level= -110 dBm, DANL=-150 dBm/Hz, RBW=1000 Hz, 5 Averages).

## Detecting Spectrum Analyzer Signals in the Presence of Noise

### Introduction

The basic spectrum analyzer display plots the power contained within a selectable filter bandwidth, the resolution bandwidth (RBW), as a function of frequency. The ability to make the RBW very narrow gives spectrum analyzers the ability to measure very weak signals and to pick signals out of noise. Some spectrum analyzer measurements such as spur searches are often concerned with measuring signals near the measurement noise floor. An understanding of how a spectrum analyzer handles signal near noise is necessary to obtain the most from spur searches and other low-level measurements.

### The Basic Spectrum Analyzer Plot

Consider Figure 4, where a signal at 1000 MHz is shown, and the signal exceeds the average noise level by 10 dB. It should be noted that noise is a random quantity and must be defined by its statistics and not its instantaneous value. Although the mean noise level in the plot below is at -120 dBm and the signal level is at -110 dBm, the actual instantaneous noise level can be above or below the average on successive traces or sweeps. The signal is barely discernible in the graph since the instantaneous peaks in the noise can occasionally exceed the signal.

### Trace Averaging

Averaging several traces is useful in reducing the noise excursions about the mean. When traces are averaged, the constant signal is reinforced while the noise takes on random values with each successive trace or sweep. Increasing the number of averages reduces the noise fluctuations. In general, averaging causes a constantly present signal to converge towards its true level and the noise to converge to its average noise power level. The noise fluctuations follow Gaussian statistics. The standard deviation of noise is reduced by the square root of the number of averages. Averaging traces increases the test times proportionally with of the number of averages.

$\sigma_N = \frac{\sigma}{\sqrt{N}}$, where N is the number of averages.

Note that the signal at 1,000 MHz in Figure 5 appears to be above its level, measuring -109.4 dBm instead of its nominal level of -110 dBm. The reason for this is that each point on the display is consists of the sum of the power in the signal and the power in the noise.

$$L_{disp}(f) = 10\ Log\left[\ P_{signal}(f) + P_{noise}(f)\right].$$

Frequency points that contain no signal will display only the noise power. Points containing a signal will display the sum.

| Name | Function | Used For | Notes |
|---|---|---|---|
| Normal | Each trace is displayed individually. | General spectrum viewing. | |
| Average ($V_{RM}$) Power average | The average of the power in M traces is converted to decibels and displayed. | Accurately measuring noise or noise-like signals. | True power averaging converges to the correct level for noise-like signals. |
| Average of Logs | The average of M traces that have individually been converted to decibels is displayed. | Traditional method of averaging spectrum analyzer traces. | This method converges to a level 2.51 dB below the true level of noise as the number of averages goes to infinity. |
| Max Hold | The maximum value of each point on the entire history of successive traces is stored and displayed. | Hunting for intermittent signals, tracing out filter responses, etc. | |
| Min Hold | The minimum value of each point on the entire history of successive traces is stored and displayed. | Looking for signal drop-outs, etc. | |

**Table 1.** Trace operations, their definitions and uses.

### Average of Power – The Correct Method

The correct method for averaging multiple traces, when examining noise or noise-like signals, is to average the power (in Watts) of each trace. The power in each trace point is computed and averaged with the corresponding point in subsequent traces. Each point on the final trace takes on a value equal to the average of the corresponding point in all the underlying traces.

$$L_{trace} = 10 * log\frac{1}{M}\left(\sum_{m=1}^{M} P_{trace}(m)\right)$$

In the equation above, *M* is the number of traces to be averaged, $P_{trace}(m)$ is the power in each trace to be averaged $L_{trace}$ is the level in dBm of the resulting trace point.

### Average of dBs: The Traditional Method

Many spectrum analyzers average traces after they've been converted to decibels. This **average of logs** stems from traditional swept spectrum analyzers that used analog logarithmic amplifiers to drive CRT displays.

$$L_{trace} = \frac{1}{M}\left(\sum_{m=1}^{M} 10 * logP_{FFT}[m]\right)$$

Average of logs converges to an error of **-2.5 dB** as the number of averages grows to infinity. This apparent reduction in the noise level is useful for finding low level signals, but cannot be used for accurate measurements near the noise, as the noise power does not correctly add to the signal power.

### Other Trace Operations

In addition to averaging, most spectrum analyzers have other useful trace operations that allow for various useful measurements and operations. Table 1 shows common trace operations, their functions, and when they are used.

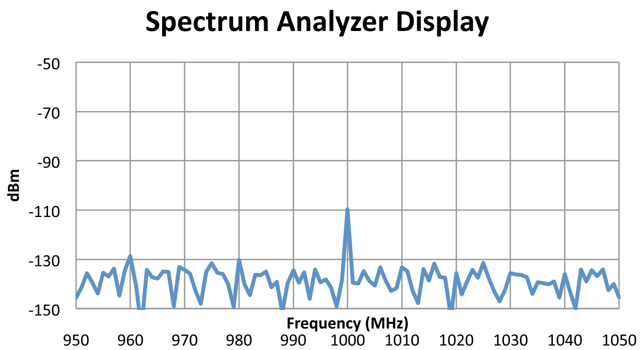


**Figure 6.** Spectrum Analyzer Trace with signal near noise
(1 GHz Signal level= -110 dBm, DANL=-150 dBm/Hz, RBW=10 Hz).

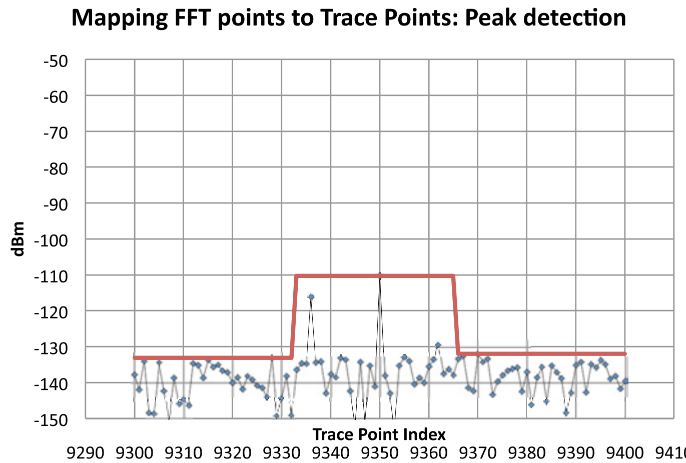


**Figure 7.** Mapping FFT points into trace points by peak detection.

### Effect of VBW

The Video Bandwidth Filter in a traditional swept spectrum analyzer filters the output of the IF level detector – see Figure 1 for the basic spectrum analyzer architecture. The VBW filter has the effect of reducing the variations in noisy signals and providing a more stable measurement of signals near noise.

FFT analyzers compute frequency components by simultaneously processing a wide IF and don't typically have an IF level detector to be filtered with a hardware VBW. FFT analyzers typically use trace averaging to achieve noise reduction. Tektronix RSA's can emulate the VBW function using a patented DSP algorithm that processes the FFT output and achieves the same noise reduction as the equivalent VBW filter.

### Effect of RBW

Noise in electronic systems follow Gaussian statistics and can be accurately modeled as White Gaussian Noise (WGN). “White” in the name refers to flat distribution of noise power over frequency. This means that the noise power is proportional to the measurement bandwidth, the RBW in the case of spectrum analyzers. A reduction in RBW produces a proportional reduction in the measured noise power but not the signal power. Reducing the RBW from 1000 Hz to 10 Hz produces a noise floor reduction of 20 dB as shown in Figure 6. The following equations express the measured noise levels in Watts and dBm.

$P_{noise\ W} = RBW_{Hz} * P_{DANL\ (Watts)}$, and

$$P_{noise\ dBm} = 10 * \log(RBW_{Hz}) + P_{DANL\ (dBm)}$$

## Converting FFT Points to Trace Points

Consider the display in Figure 7. The span is 100 MHz and the RBW is 10 Hz. This means that there are 10 million RBWs in the span. FFT based analyzers use windowing functions in their FFTs requiring a minimum of 2 FFT points per RBW. The underlying FFT in the above trace needs a greater than 20 million FFT points ($2^{25}$ = 33,554,432 points for a power of 2 FFT). Spectrum analyzers must map the large number of FFT points to a limited number of trace points in a rational manner that preserves measurement fidelity. Trace points can exceed the number of pixels in the instrument display. In this case, the graphics processing of the instrument further compresses the trace for the display. However, markers can still be used on the underlying trace points.

Consider the scenario shown in Figure 7. There are 99 FFT points that we wish to map into three trace points. Two of the FFT bins contain a signal, the reminder contain only noise. The kind of mapping used depends on the expected types of signals; this mapping is referred to as Trace Detection and will be covered in the next section. Table 2 illustrates the impact of not having a sufficient number of trace points. For a +Peak detected signal the observed noise floor will increase since the displayed point takes on the highest value in the underlying trace points. The increase can be several standard deviations (sigma). This is significant because the spur tests are often performed using a +Peak detector because of the need to capture the worst case spurs. Using a +Peak detector will increase the observed noise floor.

| RBWs / Trace Point | Number of Standard Deviations | dB Rise in Observed Noise Floor (+Peak trace detection) |
|---|---|---|
| 1.00E-01 | 1 | 0 |
| 1.00E+00 | 1 | 0 |
| 1.00E+01 | 1.28 | 2.2 |
| 1.00E+02 | 2.33 | 7.3 |
| 1.00E+03 | 3.09 | 9.8 |
| 1.00E+04 | 3.72 | 11.4 |
| 1.00E+05 | 4.26 | 12.6 |
| 1.00E+06 | 4.75 | 13.5 |
| 1.00E+07 | 5.2 | 14.3 |
| 1.00E+08 | 5.61 | 15 |

**Table 2.** The effect of mapping multiple RBWs into one trace point.

### Sinusoidal Signals: Peak Trace Detection

Sinusoidal signals map to spikes or impulses on the Spectrum Analyzer trace. If there are many FFT points that map into a single trace point as shown in Figure 7 then peak detection is the appropriate mapping. The trace point is set equal to the largest of the signals present in the underlying FFT as shown in Figure 7. One would have to narrow the span or increase the number of trace points to resolve the two signals seen in Figure 7. One should note that this mapping method also displays the peaks of noise. While the average noise level in the left-most segment is -140 dBm, the trace shows a level -134 dBm. This effect can be particularly surprising when the number of FFT points or the number of resolution bandwidths (RBW) that maps to a single display point is large. Consider the case mentioned above where each trace contains 10 Million RBWs. If the displayed trace contains 1000 points then there are 10,000 RBW's per trace point. The **peak detection mapping** will assign a value to the trace point equal to the largest of ten thousand points in the undelaying trace. This greatly exaggerates the observed noise floor. Table 2 shows the expected rise in the observed noise floor as a function of the number of the number of RBWs that map to a single trace point.

### Noise Signals: Average Trace Detection

For noise and noise-like signals, the preferred way to map multiple RBW of FFT points to trace points is averaging. This is similar to the trace averaging that was discussed previously. In average trace detection, the displayed trace point takes on the average value of all of the underlying FFT points. One must be careful how signals are averaged; keeping in mind that noise is a stochastic process that is understood by its statistical properties.

#### Average of Power - The Correct Method

The correct method of mapping multiple FFT points to a single trace point when measuring noise or noise-like signals is to average the power (in Watts) of the multiple FFT points underlying each trace point. The power in each FFT point is computed and each trace point takes on the average of all underlying FFT points. Conversion to dBm is done after the averaging process.

$$L_{trace} = 10 * log\frac{1}{N}\left(\sum_{n=1}^{N} P_{FFT}(n)\right)$$

In the equation above, $N$ is the number of FFT points per trace point, $P_{FFT}(n)$ is the power in the FFT points and $L_{trace}$ is the level of the resulting trace point.

#### Average of dBs: The Traditional Method

Many spectrum analyzers average trace points after they've been converted to decibels. This **average of logs** stems from traditional swept spectrum analyzers that used analog logarithmic amplifiers to drive CRT displays.

$$L_{trace} = \frac{1}{N}\left(\sum_{n=1}^{N} 10 * logP_{FFT}[n]\right)$$

Similarly to trace averaging, an average of logs converges to an error of **-2.5 dB** as the number of averages grows to infinity.

| Name | Function | Used For | Notes |
|---|---|---|---|
| Peak+ | The maximum value of multiple FFT points is assigned to a trace point. | General spectrum viewing. | This is the Normal Spectrum analysis mode. |
| Peak- | The minimum value of multiple FFT points is assigned to a trace point. | Searching for peak negative excursions in a signal. | |
| Average | The average value of the powers in multiple FFT points is assigned to a single trace point. Conversion to dB is done after averaging. | Measuring noise or noise like signals. | Converges to the correct average value for white Gaussian noise. |
| Average of Logs | The average value of the levels in dB of multiple FFT points is assigned to a single trace point. | Measuring noise or noise like signals. | Converges to a value 2.51 dB lower than the true average value for white Gaussian noise. |
| +/- Peak | Both the maximum and the minimum value are shown via a wide trace of via two traces. | | |
| CISPR: Quasi Peak, Average and Peak | Specialized methods used. | Standards-based RFI measurements. | |

**Table 3.** Trace detection methods and their uses.

### Other Methods of Trace Detection

In addition to averaging, most spectrum analyzers have other useful trace detection functions that allow for various useful measurements and operations. Table 3 contains the common trace detection functions and uses.

## Considering the Spurious Performance of Spectrum Analyzers

Measuring low level spurs requires care even when the spectrum analyzer's Displayed Average Noise Level has sufficient margin to perform the required measurements. All spectrum analyzers create artifacts or spurs that can appear at low levels. Some spurs are created internally by the Spectrum Analyzer's circuitry. Others are generated inside the instrument as a result of input signal interactions with internal signals and non-linear circuit behavior. These unwanted signals, typically related to harmonics of the input signal, are highly dependent on the maximum signal level present in the input, even when the large signal lies outside the displayed span.

### Residuals

*Residual Spurious* responses are internally generated spurs that exist in all spectrum analyzers and are independent of any input signal. These unwanted signal components are the result of imperfect isolation between the various signal paths inside the spectrum analyzer and can come from digital clocks, local oscillators or switching power supplies. Spectrum analyzers are regularly used to measure spurs far below their Residual Spurious specifications. One technique to account for these residual signals is to measure them by taking a spur sweep with the input terminated. The resulting list of spur locations and levels can be tabulated and then removed from the subsequent measurement results. *Residual Spurious* are expressed as an absolute power level, specified in dBm. This means they do not change level with any input. The specification for the RSA6120B is -90 dBm for frequencies from 40 MHz to 200MHz, and -95 dBm (-110 dBm Typical) from 200 MHz to 20 GHz. These signals must be well understood to ensure they are not mistakenly included in the results as they may not be from the DUT.

## Spurious with Signal

*Spurious with Signal Present or signal-related spurs* are the result of unintended interactions between the input signal and the various internal clocks and local oscillators that are part of the spectrum analyzer's circuitry. Most signal-related spurs are caused by non-linear behavior in the spectrum analyzer's circuitry and are highly dependent on the levels of signals present at the spectrum analyzer input. There are several types of signal-related spurs which are often specified separately. They include *image rejection, harmonics, third order intermodulation, second order intermodulation, etc.* The specifications for signal-related spurs are usually in terms of dB below the input signal level or dBc. Signal related spurs specifications are especially relevant if a low level spur search must be made in the presence of a high level signal. Measuring spurs in a transmitter output, for example, may require the measurement of spurs at the -120 dBm level as in our example while the transmitters intended output signal has a power of several watts. In these cases, it might be required to filter out the transmitter's signal (notch filter) to make sure that its level does not exceed the input level specified in the analyzer's spurious specifications.

All spectrum analyzers publish spurious with signal specifications that vary with acquisition BW and input frequency at a specified level of input signal. The RSA6120B, for example, performance varies from -78 dBc to -70 dBc depending settings with a maximum signal level of -25 dBm after RF attenuation. The option 51 preamplifier, when used, would typically achieve similar performance with a maximum input signal at approximately a 30 dB lower level.

## Harmonics

These unwanted signals can appear whenever the analyzer is tuned to N times the frequency of a signal present at the input (N is an integer). The most relevant is the 2nd-harmonic specification (N=2). The RSA6100B Series specifies 80 dBc harmonics for -25 dBm input signals with no RF attenuation and preamplifier off. The Option 51 preamplifier, when used, would typically achieve similar performance with a maximum input signal at -55 dBm with no RF attenuation.

Predicting the spurious behavior with Input is usually more difficult than harmonics or residual spurious. A detailed analysis requires knowledge of the frequency conversion stages internal to the Spectrum Analyzer (Local Oscillators, IF frequencies, ADC clocks, etc.) These kinds of spurs will be present at frequencies related the mixing of internal frequencies and harmonics of the input. For example, if one of the local oscillators in a spectrum analyzer is at 9 GHz, then signals harmonically related to the combination of the input signal and 9 GHz could show up as spurs.

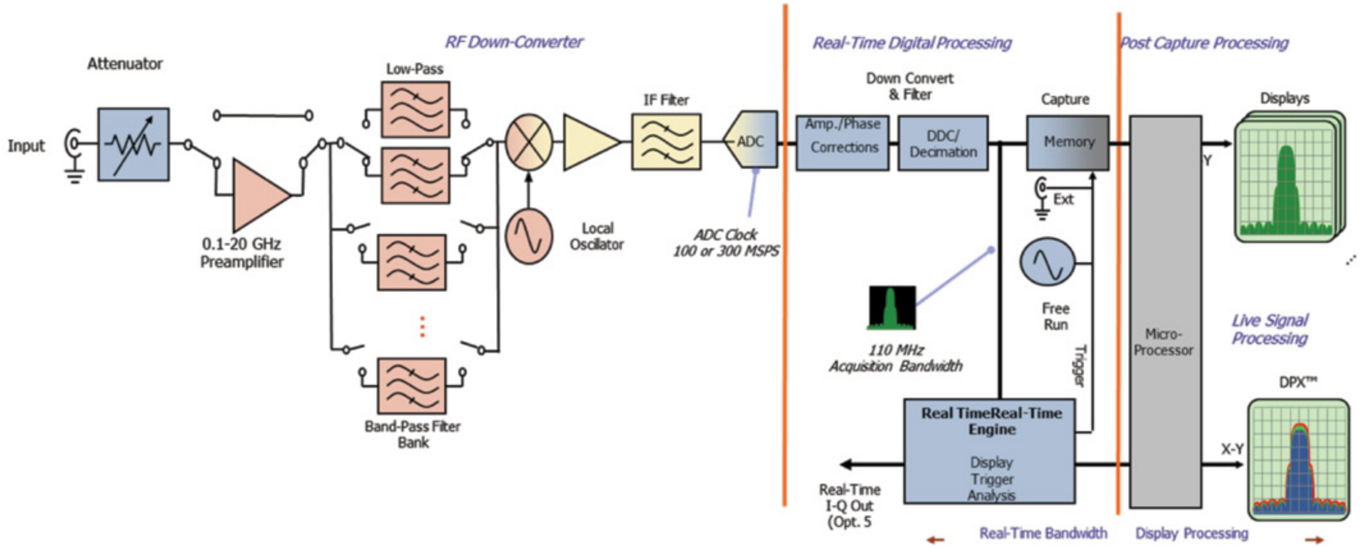


**Figure 8.** Block diagram of the Tektronix RSA6100 Real-Time Signal Analyzer.

## Tektronix Real-Time Signal Analyzers Take a Different Approach

The Real-Time Signal Analyzers perform the conventional spectrum analyzer measurements with all the expected controls and functions like multiple traces, a variety of detectors, as well as controls for RBW and VBW settings. Real-Time Signal Analyzers operate using a wide band architecture and FFT processing to improve the speed of spectrum measurements like low level spur searches. Figure 8 shows a block diagram of the Tektronix RSA6100 series Real-Time Signal Analyzer. This analyzer uses a 120 MHz wide intermediate frequency down conversion chain, then digitizes at 300 Mega Samples per second. This allows 110 MHz bandwidths to be processed digitally. For resolution bandwidth settings below about 30 kHz, the RSA's sweep time becomes much faster than swept systems because larger portions of the bandwidth are processed at any one time. To realize a sweep, the RSA actually processes steps of approximately 90 MHz and "stitches" them together across the frequency span of interest (up to 20 GHz). The individual stitches are overlapped allowing for adjacent stitches to be accurately joined at the boundary without spectrum artifacts. This approach of taking wideband acquisitions, stepping the center frequency and stitching the sequence of spectrums together allow for much faster coverage of wide spans with narrow RBWs.

Consider a 1 GHz sweep done by the RSA6100 using a 1 KHz RBW setting. This low RBW is required to achieve a low measurement floor for a spur search as described in the introduction. When the RSA6100's optimization is set for Fastest Sweep Speed, the analyzer takes a series of 90 MHz frequency steps across the 1 GHz span. For each 90 MHz step, the analyzer will store enough signal duration to realize the FFT for a particular RBW setting. The 1 KHz RBW In this example requires that the analyzer acquire a 2.6 millisecond time record at each frequency step. The RSA6100B will complete the 1 GHz span in approximately 3 seconds while providing a DANL (average detection) of approximately -140 dBm when using the optional internal preamplifier. For comparison, one legacy swept spectrum analyzer requires more than 1000 seconds to complete a similar sweep. A 1 KHz RBW is enough to easily expose -125 dBm spurs in both analyzers.

| | DANL in a 1 Hz BW (average detection) | RBW Used | Preamp used? | DANL in the RBW used | Useful spur measurement level | Measurement Time for 1 GHz sweep |
|---|---|---|---|---|---|---|
| RSA6120B | -145 dBm @ 10 GHz | 1 KHz | No | -115 dBm | -100 dBm | 3 seconds |
| RSA6120B | -162 dBm @ 10 GHz | 1 KHz | Yes | -132 dBm | -117 dBm | 3 seconds |
| RSA6120B | -145 dBm @ 10 GHz | 100 Hz | No | -125 dBm | -110 dBm | 28 seconds |
| RSA6120B | -162 dBm @ 10 GHz | 100 Hz | Yes | -142 dBm | -127 dBm | 28 seconds |
| RSA5106A | -150 dBm @ 5 GHz | 1 KHz | No | -120 dBm | -105 dBm | 5 seconds |
| RSA5106A | -162 dBm @ 5 GHz | 1 KHz | Yes | -132 dBm | -117 dBm | 5 Seconds |
| RSA5106A | -150 dBm @ 5 GHz | 100 Hz | No | -130 dBm | -115 dBm | 40 seconds |
| RSA5106A | -162 dBm @ 5 GHz | 100 Hz | Yes | -142 dBm | -127 dBm | 40 seconds |

**Table 4.** Comparison of the constituent RF specifications required to complete a spur search test.

Some performance data for Real-Time Spectrum Analyzers can be seen in Table 4. Comparable sweep and RBW settings on conventional swept analyzers run in the hundreds or thousands of seconds. The faster sweep times compared to legacy spectrum analyzers point to a business case where thousands of hours of test time reduction can significantly help reduce program costs and ensure the project meets the delivery dates.

| | Legacy swept SA | Current SA with FFT | Tektronix RSA6120B |
|---|---|---|---|
| Minimum spur measurement level required | -135 dBm | -135 dBm | -135 dBm |
| Measurement time to cover 20 GHz | 522 minutes | 29 minutes | 5 minutes |

**Table 5.** Relative test time benchmark results for different spectrum analyzers.

## A Spur Search Case Study with Tektronix RSA6120B

With increasingly demanding schedules, pressure on program costs, and the pace of advancing technology, the pressure is very high. Mitigating risks to development and production effort include ensuring that the program completes in time, that a satellite launch date is met or that a new product ships to market in time. Spur searches contribute a significant fraction of overall test time. In one case involving microwave communications equipment, the spur search contributed over 500 hours of test time per unit to complete the tests in various environmental conditions. The 500 hours only includes the actual time testing a device and not any additional time related reworking the device after a failure. The actual time required to recover from a failed test could add additional hours.

This measurement required all spurs greater than -135 dBm to be measured across a frequency range that covered near DC to Ku band. This is beyond all of the Spurious Performance specifications for all of the spectrum analyzers that were considered. Several techniques were used to characterize the analyzers performance and decide which of the displayed spurs were related to the device under test and which spurs were related to the instrument.

In all cases the measurement was made in segments with the RBW in each segment optimized to meet the minimum spur measurement level required while maintaining the fastest measurement speed.

By using the Tektronix Real-Time Signal Analyzer, the total test time was reduced from over 12 weeks to a matter of days. This is because the low level spur search could be accomplished in a much shorter period of time. The test time savings resulted in a shifting of the test budget to go after the next critical items on the test plan – additional people could be hired while the program was kept under budget and schedules were pulled in.

Not every case will be this dramatic, but the spur search will often be the lengthiest test in a test procedure. Results will depend mainly on the RBW required for a particular test, which is a function of the instrument used and the noise floor required. The Tektronix Real-Time Signal Analyzer has a wide band architecture and high RF performance that allows for significantly faster test times.

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**For Further Information**
Tektronix maintains a comprehensive, constantly expanding collection of application notes, technical briefs and other resources to help engineers working on the cutting edge of technology. Please visit **www.tektronix.com**




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