Using Fast-Sweep Techniques to Accelerate Spur Searches

Application Note

Agilent Technologies
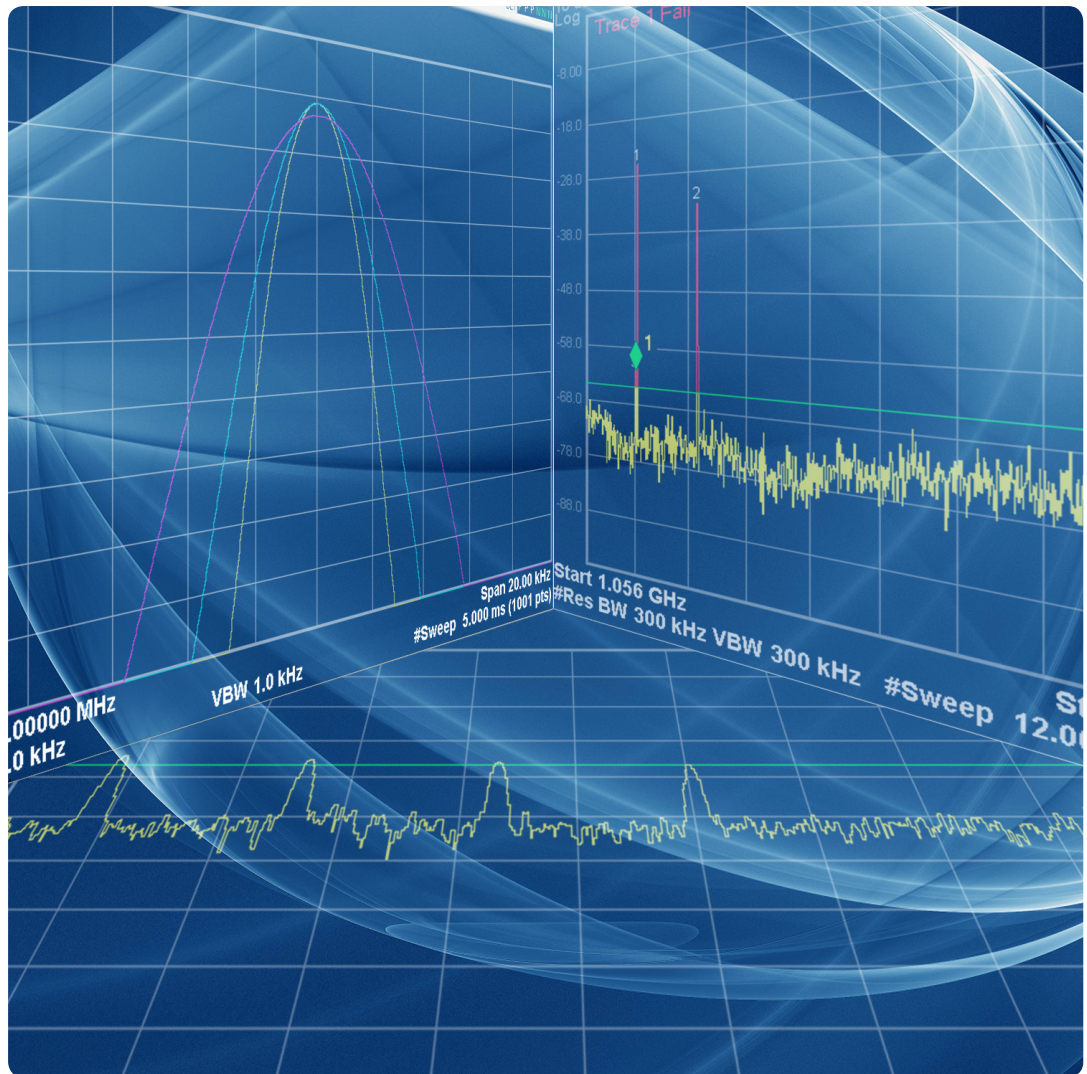
Introduction

Measurement speed is a major issue for a wide variety of RF and microwave products, and this influences production costs in industries ranging from commercial wireless to aerospace and defense. As a result, manufacturers in these areas are looking for ways to shorten design cycles, reduce manufacturing costs and increase yield.

One important opportunity for improvement is the search for spurious emissions. These tests can be especially difficult and time-consuming because measurements must be made over wide frequency ranges and with high sensitivity. Unlike measurements of harmonics, the locations of spurious signals are not accurately known beforehand and there is often no choice but to sweep across wide frequency spans using narrow resolution bandwidths. In addition, the amplitudes of spurious signals are often near the measured noise floor, creating challenges for measurement accuracy and repeatability.

The most commonly used tool for such measurements is an RF/microwave spectrum or signal analyzer. In recent years, the technological evolution of these analyzers has enabled faster spurious measurements. For example, high-speed analog-to-digital conversion and digital signal processing (DSP) has supplanted analog technology with digital intermediate frequency (IF) sections and therefore digital resolution bandwidth (RBW) filters.

Digital filtering can provide some special benefits for narrow-RBW, wide-span operations such as spurious measurements. For example, existing digital filters have a better shape factor and can maintain full accuracy while being swept several times faster than equivalent analog filters. This technique is called oversweep.

The latest advances in signal processing provide remarkable improvements in sweep speeds by implementing a new type of digital RBW filter in Agilent's PXA, MXA and EXA X-Series signal analyzers.[1] This new filter allows sweep speeds to be up to 50 times faster without compromising accuracy in terms of amplitude and frequency. This application note focuses on this new technology and its use for spurious measurements.

1. The fast-sweep filtering technique is available in all PXA models and in MXA and EXA models configured with options MPB, DP2 or B40.

Reviewing current problems and practices in spur measurements

RF performance requirements are steadily increasing, driven by demand for greater communications throughput and wider bandwidths within the realities of a crowded spectral environment that places tight limits on undesirable emissions. The densely populated shared spectrum increases the likelihood that excessive spurious and harmonic signals will be both troublesome and noticed.

One way to understand the optimization of RF testing across the life cycle of a typical product is to separate the process into three stages: R&D, design validation and manufacturing. In R&D, RF testing is typically done manually on one to several prototypes and speed is rarely a major consideration.

In design validation, a pilot run of tens to hundreds of units may be produced. Characterization of these units includes spur measurements (frequency and amplitude) using a narrow RBW and autocoupled sweep-time rules over a span of interest, often from the fundamental to the tenth harmonic. This wide frequency survey provides accurate information about all spurs generated by the product.

With current practice, this "spur characterization" process is performed in a single pass over the frequency range of interest and the use of standard sweep rates ensures that the measurements are accurate per the specifications of the spectrum analyzer. However, the use of these slower sweep rates results in measurement times that are not acceptable when the product is transferred to manufacturing.

In an efficient manufacturing process, thousands to millions of products are built and tested as quickly as possible across a wide span versus a pass/fail limit determined by a spurious-free dynamic range (SFDR) specification that is often derived from a published standard. The limits are sometimes described in terms of a spectral mask or spectrum emission mask (SEM). Highly stringent SFDR specifications demand clear separation of spurious signals from noise: this requires the use of narrower RBWs, which result in slower tests. Because sweep rates for RBW filters generally vary with the square of the RBW, finer resolution results in dramatically slower sweep rates and longer measurement times.

Accelerating spurious measurements

In the last 20 years, spectrum analyzers have made increasing use of digital technologies, especially DSP, to improve measurement speed and performance. In addition to the digital IF filters and oversweep mentioned previously, some have implemented techniques that subtract noise power, thereby reducing the effect of broadband noise on measurements of low-level signals. This subtraction can be performed manually or automatically as in the "noise floor extension" (NFE) feature of the Agilent PXA X-Series signal analyzer.[1]

These signal-processing technologies can be used to enhance high-performance and midrange signal analyzers without requiring expensive improvements in analog circuits. With either class of analyzer, the advanced technology expands the performance envelope, offering new levels of productivity through the optimization of the tradeoffs between measurement speed, accuracy, repeatability, and so on.

The latest advances in signal processing provide considerable improvements in sweep speeds by implementing a new type of digital RBW filter. The new filter allows sweep speeds to be up to 50 times faster without compromising accuracy in terms of amplitude and frequency with the new filter (see sweep times at lower-right beneath each trace).
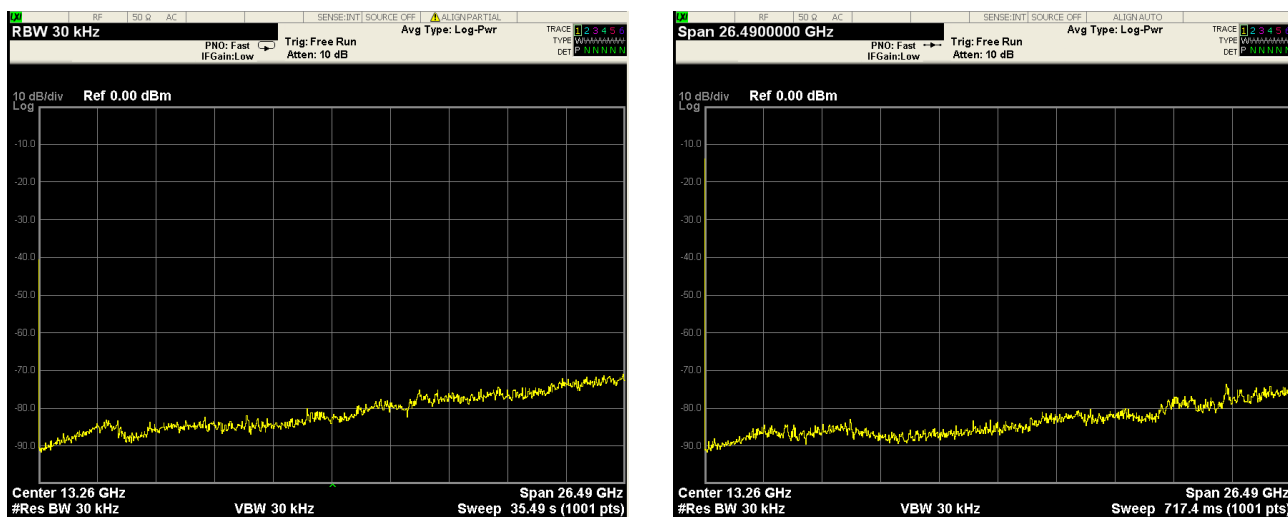

Figure 1a. On the left, sweeping the full 26.5-GHz frequency range of a spectrum analyzer using a 30-kHz RBW filter requires 35.49 seconds when using existing digital filter technology.

Figure 1b. On the right, the same sweep performed with new digital filter technology takes 717 ms, a speed improvement of more than 49 times.

Applications such as spur searches that require sweeps over wide spans using resolution bandwidths in the range of several to hundreds of kilohertz will benefit greatly from this new technology. Although spurious measurements are perhaps the most likely to benefit from this speed advantage, any measurements that require wide frequency spans and narrow RBWs—whether to reduce noise floor or resolve closely-spaced signals—will see substantial speed improvements.

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1.   See application note Using Noise Floor Extension in the Agilent PXA Signal Analyzer, Agilent literature number 5990-5340EN

Using oversweep and a two-pass approach: A partial solution

One way to accelerate spurious testing in existing analyzers that have digital filters—but not the fast-sweep technology—is to utilize the speed of a large amount of oversweeping and compensate for the resulting errors by measuring the desired frequency range in two passes, using different measurement configurations and test limits. Even with two passes, the total measurement time is significantly shorter than when sweeping at a normal autocoupled rate that provides accurate results in one pass.

First, the frequency range in question is measured using oversweeping and a wide RBW. In these measurements, the oversweeping involves a sweep rate several times faster than the autocoupled value over wide frequency spans. This produces at least three types of errors:

- Low amplitude: The displayed amplitude of the spurious and other signals is lower than the true value, and by an amount larger than the analyzer specifications would indicate.

- Bandwidth spreading: The effective RBW of the measurement is significantly wider than the selected value.

- Frequency shift: The apparent center frequency of spurious and other signals is higher than the true value, and by an amount larger than the analyzer specifications would indicate.

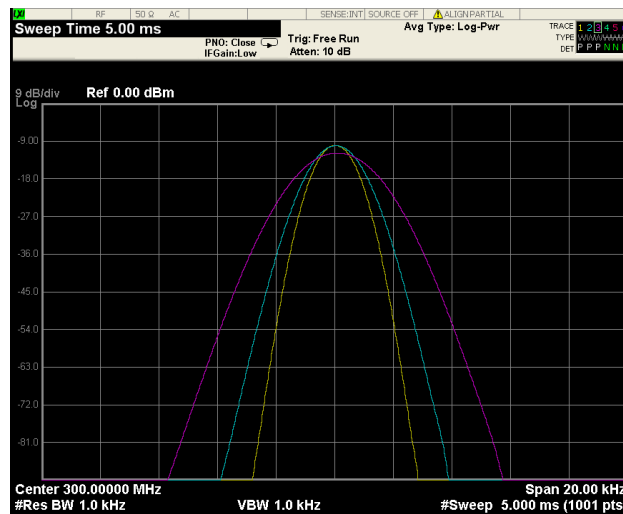Examples of autocoupled and overswept measurements are shown in Figure 2.

Figure 2. Oversweeping produces errors in frequency, amplitude and bandwidth spreading. The frequency error can be calculated and corrected.

This first-pass measurement can be made much more quickly than when using autocoupled RBWs and sweep times, and can effectively locate spurious signals in frequency. DSP in the spectrum analyzer can correct the frequency-shift error, providing accurate measurements of signal frequencies.

Unfortunately, the amplitude and bandwidth-spreading errors cannot be corrected in this oversweeping configuration, and a second measurement pass is required to obtain accurate measurements. In addition, the low-amplitude error requires that the first-pass spurious test limit be lowered accordingly.

The second pass in this measurement approach is made by using narrower RBWs to distinguish spurious signals from harmonics and by setting the sweep time to the autocoupled value. The analyzer is selectively tuned to measure only the previously found limit failures. Finally, harmonics are tested versus a separate set of limits. Because only the limit failures are tested in very narrow spans, the total measurement time for this two-pass approach can be shorter than for a single-pass approach using narrow RBWs and autocoupled sweep times. An example of this two-pass approach is illustrated in Figures 3a, 3b and 3c.
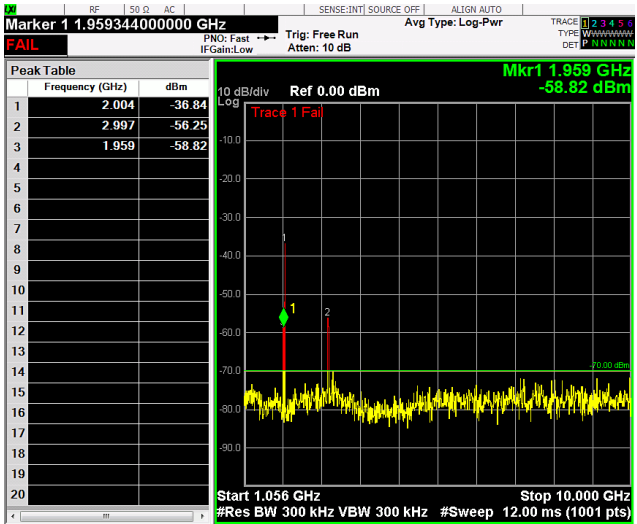

Figure 3a. In the two-pass technique, spurious signals are first identified during a fast sweep using a high degree of oversweeping. In this measurement, 10x oversweeping was used with a 300 kHz RBW and a limit line set 5 dB lower to account for the loss in apparent amplitude due to oversweeping.
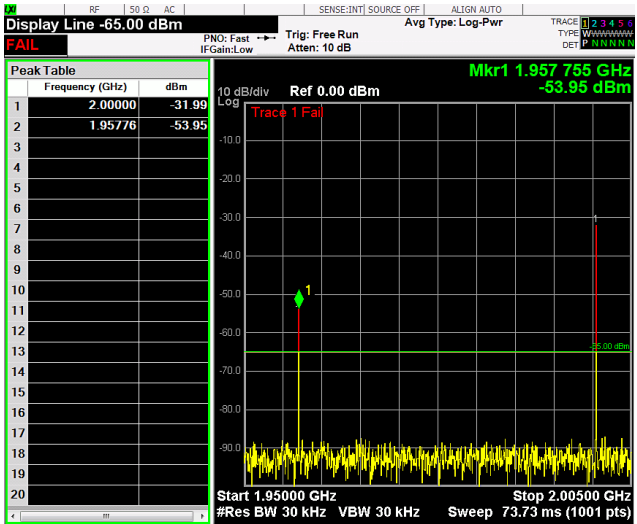

Figure 3b. Because oversweeping produces measurement errors, the spurs identified in the first pass are measured separately in a second pass configured for accuracy. Sweeping this 10 MHz span using autocoupled sweep time rules and a 30 kHz RBW requires 73.73 ms. Notice that the narrower RBW and slower sweep increases measurement dynamic range and accuracy. Accordingly, the limit line has been increased by 5 dB.
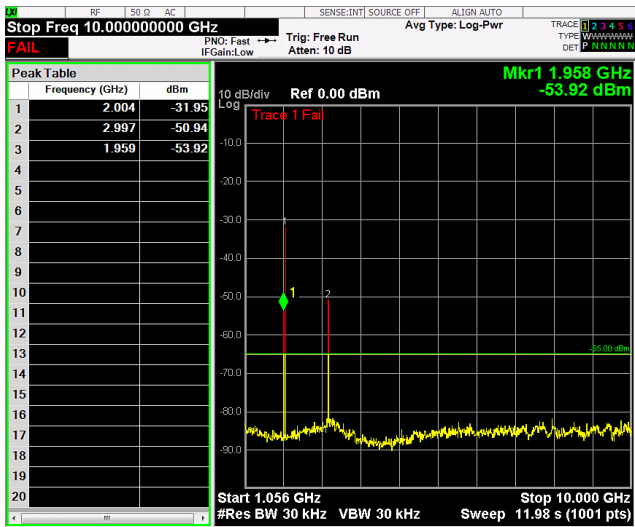
Figure 3c. For comparison, this trace shows a traditional single-pass measurement with full accuracy. The 12-second measurement time is much longer than the two-pass approach shown in 3a and 3b.

While this multi-pass technique can significantly increase test speed, it adds complexity to the design and execution of the tests. It also requires customized test limits and tracking of specific spurious frequencies.

Implementing RBW filters that can be swept at much higher rates without errors offers the benefit of making faster measurements in a single pass. These fast-sweeping filters and the measurement approaches to take advantage of them are described in the remaining sections of this application note.

Going faster: Agilent's fast-sweep technique

To extract maximum benefit from Agilent's fast-sweep technology, it's useful to have an overview of two things: IF processing in spectrum and signal analyzers, and the ways in which DSP can enhance IF performance.

DSP-rich signal analyzers perform resolution bandwidth filtering digitally on the final analog IF signal. The signal is first fed through analog pre-filtering and amplitude ranging and is then digitized with high resolution and linearity.[1] The high-quality, digital version of the IF signal offers several advantages. First, you have precise control over resolution bandwidth (versus the ± 10-20 percent of analog filters) and therefore better control over the analyzer's displayed average noise level (DANL) and sweep speed. Second, when you choose a narrow resolution bandwidth or span, the analyzer can automatically switch to a fixed or stepped local oscillator (LO) and FFT processing to further improve sweep speed while maintaining accuracy. The combination of FFT analysis for narrow spans or resolution bandwidths and swept analysis for wider resolution bandwidths and spans allows sweeps to be optimized for the fastest possible measurements.
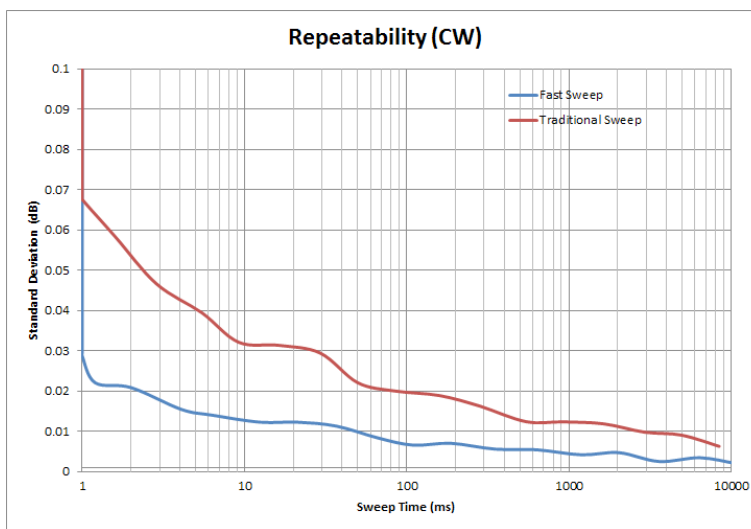
RBW filtering for fast sweep

In the past, spectrum analyzers used a fixed RBW filter for all sweep rates. This required that the analyzer LO was swept slowly enough to prevent oversweeping and thereby ensure that it detected the correct amplitude and bandwidth of the signal. During fast sweep, the phase response of the RBW filter is adjusted based on the sweep rate to compensate for oversweeping effects. This maintains the correct amplitude and bandwidth of the detected signal, even at very high sweep rates.

Improving repeatability

The fast sweep rates enabled by chirp-IF processing provide another benefit: improved measurement repeatability for equivalent sweep times. Holding sweep time constant while using a narrower RBW to measure CW signals reduces measurement variance because the narrower filter blocks more of the broadband noise.

Since sweeps with equivalent accuracy can be performed in much less time, the repeatability of spectrum measurements is much less dependent on sweep time. Figure 4 summarizes two families of measurements—one traditional and the other fast sweep—that demonstrate the difference. For CW spurious measurements over a given measurement or sweep time, the difference in repeatability is one clear benefit of an improved SNR due to the narrower RBW.

Figure 4. Comparing fast sweep to traditional sweep, the lower values and shallower slope of the blue data points (fast sweep) show that repeatability is improved and varies less with sweep time.

1.   Page 34 of Agilent Application Note 150, Spectrum Analyzer Basics, literature number 5952-0292

Repeatability is an important factor in measurement accuracy and in the time required to perform a given measurement. For example, better repeatability can help improve measurement speed and can simplify the design of measurement routines due to the dramatically reduced dependence of repeatability on sweep time. Figure 4 shows that over a wide range of sweep times, the repeatability of Agilent's fast-sweep technique is (in dB terms) approximately two to three times better.

In summary, Agilent's fast-sweep technology provides at least four important benefits:

- Dramatically reduced sweep times for measurement configurations such as wide spans and narrow RBWs

- Improved measurement throughput while maintaining accuracy, frequency selectivity and consistent bandwidth

- Improved measurement repeatability at faster sweep rates

- Simplified selection of RBW to get a desired combination of dynamic range and repeatability, because repeatability depends almost entirely on dynamic range rather than both dynamic range and sweep time

Applying fast-sweep technology to spurious testing

In the two-pass example described earlier, the first pass—fast sweep rates, wide RBW, wide span—required a follow-up set of measurements with narrow RBWs. The second pass was needed to accurately measure spurious amplitudes and distinguish them from harmonics so both could be tested against appropriate limits. The amplitude effects of oversweeping also required a different set of limits for the two measurement passes.

By allowing much greater amounts of oversweeping while compensating for its effects, the Agilent fast-sweep technology changes the tradeoffs between speed, accuracy and resolution. Spurious characterizations that rely on narrow RBWs in wide spans can now be completed up to 50 times faster using a single-pass approach and a single set of test limits for spurious signals.

Spurious tests and associated harmonic-distortion measurements can now be faster and less complicated, as shown in Figure 5. Spurious signals can be distinguished from harmonics without the need to re-measure using a narrower RBW. Generally, one limit line can be used for spuious signals, while failures due to harmonics will be ignored and the harmonics themselves will be measured using a list sweep or a dedicated harmonic-measurement routine.
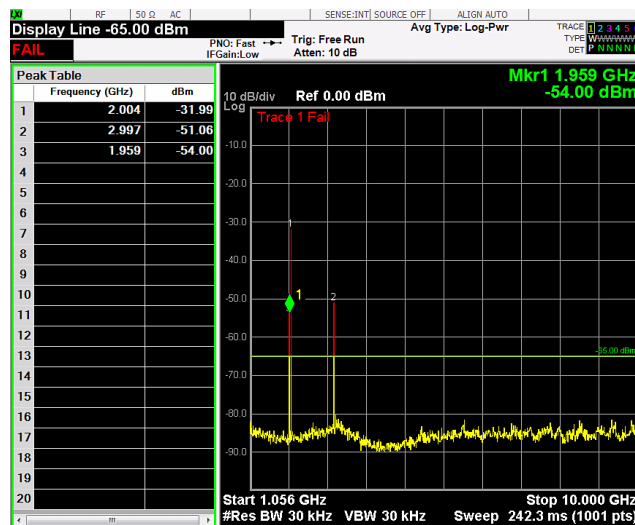

Figure 5. Because the fast-sweep technology allows a single measurement pass to accomplish what previously required two passes, only a single set of spurious limits is needed.

Using the built-in measurement function

Agilent X-Series signal analyzers include PowerSuite, which is a set of simple, intuitive one-button measurements for channel power, harmonic distortion, spurious emissions, and more. In the spurious emissions mode, you can configure a set of up to 20 frequency ranges, each with different settings for peak threshold, peak excursion, amplitude limits, trace detectors and RBW.

Two detectors can be used simultaneously in each range, making it easier to measure different types of spurs in the same range or to produce different detection statistics on each spur. After a measurement is complete, you can loop back through each spur and view the trace associated with it.

In viewing the results, all measurement ranges can be concatenated and visualized as a single trace. This display feature avoids the need to sweep continuously through a large span or manually step through multiple spans, both of which can be time-consuming and inefficient. Figure 6 shows an example of an automated spurious measurement implementing multiple frequency ranges and measurement bandwidths.
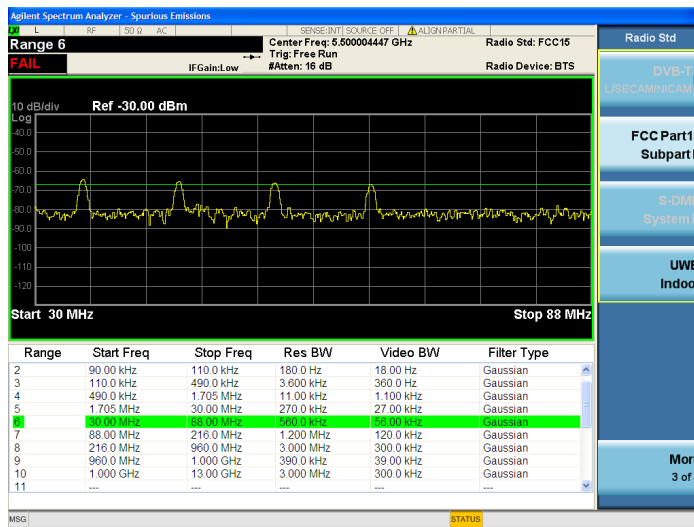

Figure 6. With the X-Series' one-button spurious measurements, multiple frequency ranges can be tested separately using different measurement parameters. The results of the measurement ranges can be viewed separately (here range 6 is shown on the trace) or concatenated to form a single trace.

Optimizing automated spurious measurements

Spurious testing is often conducted over a frequency range extending to the tenth harmonic of the operating frequency of a device, while excluding the fundamental itself and higher harmonics. Because some of these harmonically-related signals have much greater amplitude levels than spurs, judicious adjustments of start frequency, stop frequency and input attenuation can improve sensitivity and thus help ensure the best speed and dynamic range for spurious measurements.

A common way to avoid measuring the harmonics is to make multiple sweeps centered between the harmonics, keeping those signals in the skirts of the RBW filters at the sweep start and stop frequencies. With this approach, the measurement of a 1-GHz device would require 10 sweeps and nine changes in center frequency. The key to measurement efficiency is to sweep as quickly as possible while maintaining measurement statistics that correspond to the desired DUT pass/fail confidence interval.

The power of the fundamental is measured separately and the goal is to measure the low-level spurious signals as accurately and efficiently as possible. Consequently, the power at the analyzer's input mixer should be set based on the largest harmonics and not the fundamental. In addition, because harmonic distortion due to the signal analyzer shows up at the harmonics of the DUT fundamental, the analyzer-contributed harmonic distortion can be ignored when making spurious measurements.

When analyzer harmonic distortion is not a consideration, the power at the analyzer input can be increased beyond typical values by using less attenuation. A maximum power level of +5 dBm at the analyzer input mixer will result in some input compression and harmonic distortion; however, the harmonic distortion can be ignored and the higher input level will improve analyzer sensitivity and dynamic range for spurious measurements.

The attenuator setting can be determined with the following simple equation:

Carrier power – attenuation = +5 dBm

ADC overload due to the high power of the fundamental can be a problem with this approach. This overload is avoided by tuning the start frequency slightly above the fundamental and using the analog prefilters in the signal analyzer's IF stage to attenuate the carrier power at the ADC. The prefilters attenuate the signal prior to the digitizing of the IF signal as shown in Figure 7.
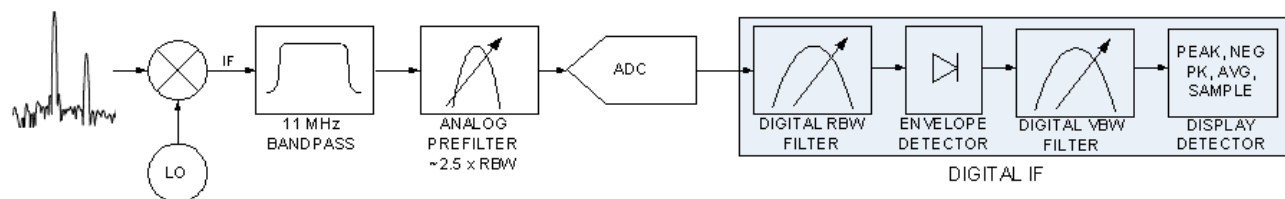

Figure 7. This block diagram of a signal analyzer IF section shows the position of the analog prefilter. It and the bandpass filter can be used to attenuate out-of-band signals and avoid ADC overload, allowing the ADC input range to be set to a lower value and improving sensitivity.

It's also necessary to reduce the stop frequency to a value slightly lower than the second harmonic. This can be done by subtracting RBW/2 from the stop frequency. By tuning away from the fundamental and second harmonic, measured results will include only the desired spurious frequency range and a spurious limit line will be a valid pass/fail indicator. To conduct the rest of the spur search between the second, third and subsequent harmonics, it is necessary to retune only the center frequency.

A detailed example of this process is presented in the appendix at the end of the note.

Configuring detectors, bandwidth and sweep time

In addition to configuring the signal analyzer input to optimize sensitivity for spurious signals, it is also important to choose appropriate settings for peak search, DANL, signal-to-noise ratio (SNR) and sweep time.

When searching for spurious signals, the peak detector (a type of trace detector) is always selected to ensure that the peak is found and CW power is reported accurately for each display bin in the analyzer's measurement trace.

The next step is to choose an RBW to provide adequate measurement dynamic range for the DUT's SFDR specification and for the desired measurement repeatability. Repeatability is an issue because the spurious signals are small and often close to the noise floor, causing measurements of their amplitude to be be noisy.

Since measurement repeatability in spur search depends on dynamic range and since dynamic range is improved by reducing resolution bandwidth, improving repeatibility has traditionally caused a large increase in measurement time. However when using fast sweep, sweep speed is much less dependent on RBW and thus repeatability can be increased with much less cost in measurement time

Conclusion

Increasingly, sophisticated signal processing can be used to improve fundamental parameters such as measurement speed and repeatability in signal analyzers that have a digital IF section. In the PXA signal analyzer, the fast-sweep technique can accelerate spur measurements while compensating for the amplitude, frequency and bandwidth effects of the sweep rates.

The dramatic increase in sweep rates increases the performance envelope of the signal analyzer and changes the tradeoffs available to the manufacturing engineer. In many cases, the fast sweep can be used to switch from a multi-pass measurement approach to a faster and simpler single-pass technique.

Of particular interest may be the improved measurement repeatability enabled by the fast-sweep technique. This improvement often translates into decreased measurement time to achieve a given measurement confidence band.

The fast-sweep capability also can be used in any measurement that requires a wide frequency span and a very narrow RBW, either to reduce DANL or to separate and measure closely spaced signals.

Appendix: Optimizing instrument settings for spur measurements

Because some of the harmonically-related signals have greater amplitude levels than spurs, careful adjustments of start frequency, stop frequency and input attenuation can improve sensitivity and thereby help ensure the best speed and dynamic range for spurious measurements. These steps can be performed manually or under programmatic control.

A measurement example with the analyzer configured to measure the fundamental is shown in Figure A1. In this case, the analyzer is sweeping from the fundamental to the second harmonic with the input attenuation set to 26 dB to handle the power of the fundamental (1 GHz, +10 dBm). The fundamental and second harmonic appear at the edges of the display and, in an automated system, both will be reported as spurs by a ":CALC:DATA:PEAK?" command—and this will cause the instrument to indicate a DUT test failure.
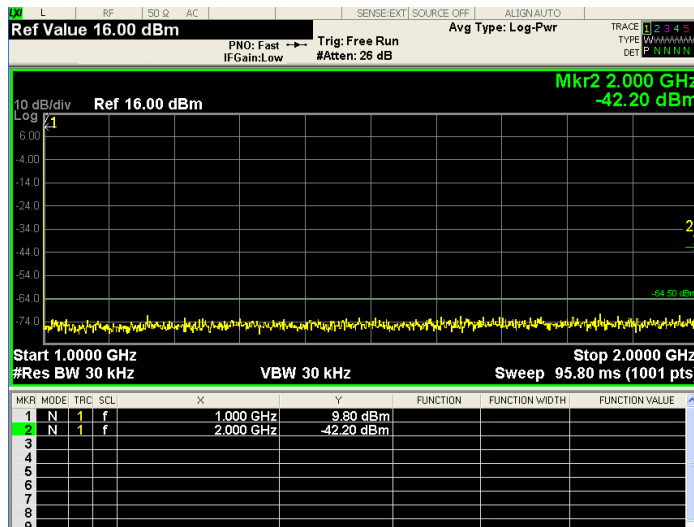

Figure A1. With the indicated frequency and attenuation settings, the measurement will fail the spurious test limit. Also, because the attenuation is not optimized for measuring spurious signals, none will be found. The analyzer was set in 'accuracy' sweep time rules for this measurement. 'Accuracy' sweep time rules provide warranted measurements at the cost of slower sweep. Fast sweep greatly improves sweep speed in 'accuracy' sweep time rules also. See X-series analyzer specification guides for more information.

Reducing the attenuation setting to optimize the analyzer for spurious sensitivity produces an "Input Overload" warning (Figure A2, lower right). The power to the analyzer's input mixer is now +4 dBm and the measured noise floor has dropped considerably due to the lower attenuation. However, the fundamental and second harmonic are still inside the measured span and the fundamental amplitude reads inaccurately due to the overload.
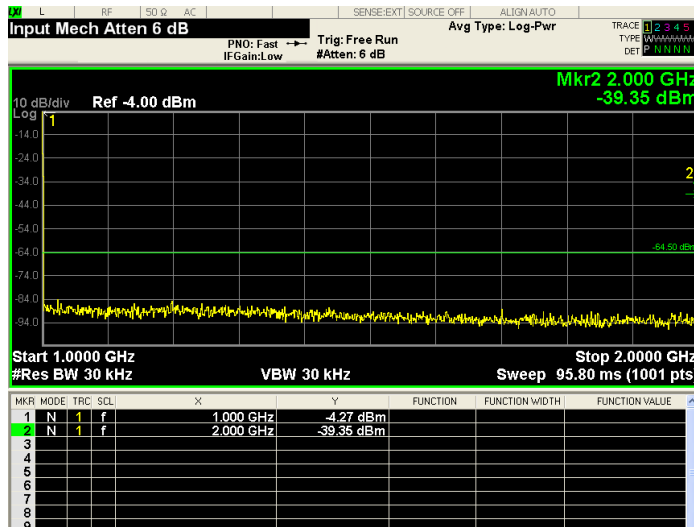
Figure A2. An input attenuation setting optimized for spurious measurements will result in an input overload if the signal fundamental is included in the measured frequency span.

The IF overload can be avoided by tuning the start frequency into the stopband of the bandpass prefilter shown previously in Figure 7 (Figure A3, below). When the start frequency is adjusted to 1.005 GHz, the IF overload is removed and the fundamental is no longer included in the spur search (Figure A4).
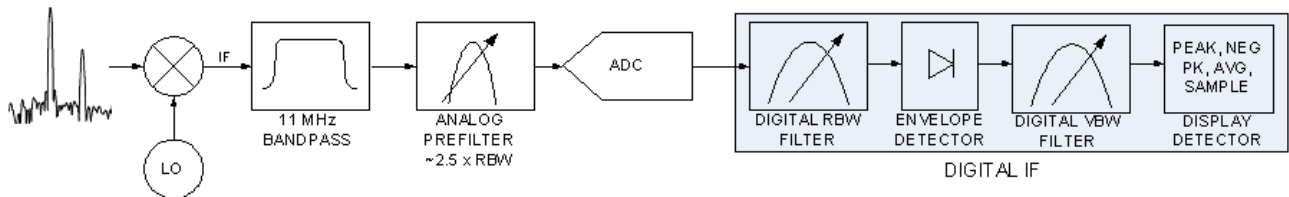

Figure A3. The analog prefilter and the bandpass filter can be used to attenuate out-of-band signals and avoid ADC overload, allowing the ADC input range to be set to a lower value and improving sensitivity.
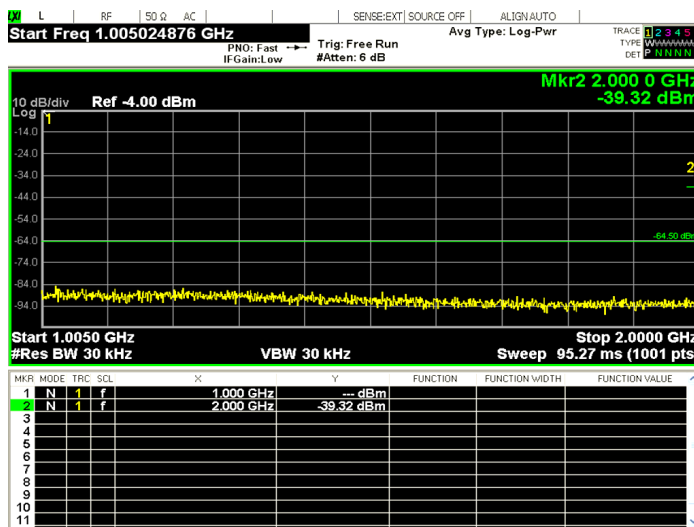

Figure A4. Tuning the start frequency away from the fundamental removes it from the measurement and causes it be attenuated. This allows attenuation to be reduced and spurious sensitivity to be increased substantially.

The next step is to remove the second harmonic from the measurement by subtracting RBW/2 from the stop frequency. Because the RBW is 30 kHz, the adjusted stop frequency is 1.999985 GHz. Measured results now include only the desired spurious frequency range and the spurious limit line is a valid pass/fail indicator (Figure A5).
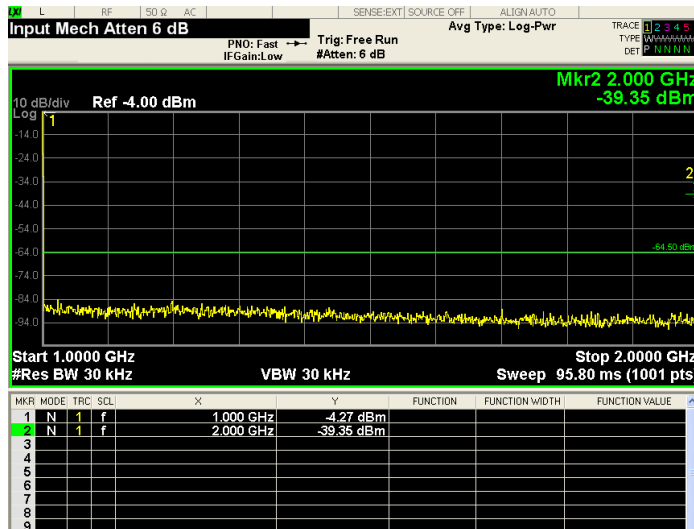

Figure A5. Reducing the stop frequency by RBW/2 removes the second harmonic from the measurement. The attenuation and measured frequency span are now optimized for spurious measurements and limit testing will show failures due only to spurious signals. Note that the actual stop frequency of 1.999985 GHz is rounded to 2.0000 GHz in the display.

To conduct the rest of the spur search between the second, third and subsequent harmonics, it is necessary to retune only the center frequency and, in a program, send ":INIT:IMM:" and ":CALC:DATA:PEAK?" commands to identify the spurious signals.

Related information

- Application note, *Spectrum Analysis Basics*, literature number 5952-0292

- Application note, *Spectrum and Signal Analyzer Measurements and Noise*, literature number 5966-4008E

- Brochure, N9030A *PXA X-Series Signal Analyzer*, literature number 5990-3951EN

- Brochure, *N9020A MXA X-Series Signal Analyzer*, literature number 5989-5047EN

- Brochure, *N9010A EXA X-Series Signal Analyzer*, literature number 5989-6527EN

- Brochure, *N9000A CXA X-Series Signal Analyzer*, literature number 5990-3927EN

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