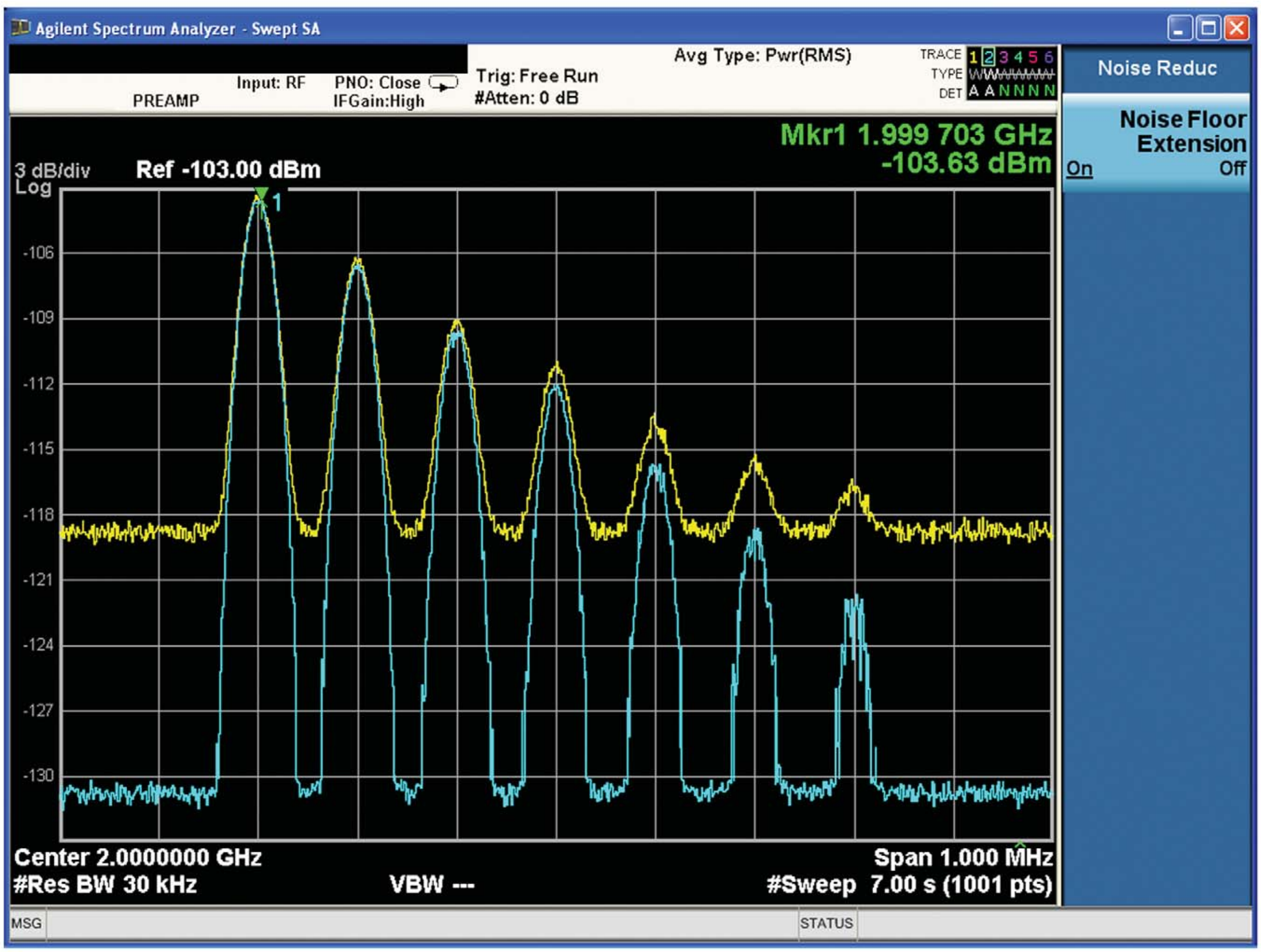
Using Noise Floor Extension in the PXA Signal Analyzer

Application Note



Agilent's Noise Floor Extension technology can provide up to 12 dB improvement in analyzer noise floor, revealing some previously hidden signals and allowing other to be more accurately measured.

Agilent Technologies

1. Overview

Dynamic range is a core measure of spectrum analyzer performance, and can significantly affect other core measures such as accuracy and measurement speed. Spectrum analyzers have many different measures of dynamic range, and most of these include noise, specifically the analyzer's own internally-generated noise. Reducing the effective analyzer noise floor therefore improves dynamic range and the quality of many measurements.

Most spectrum analyzer users are aware that any measurements made near an analyzer's displayed noise level (within about 20 dB) will be affected by noise. The analyzer's noise adds to the apparent power of the signal to be measured, producing a result that is somewhat higher than the true figure (on average) as shown in Figure 1.

The analyzer's noise also often increases the variance or "noisiness" of the result. Some users may consider the errors from the analyzer's noise contribution to be negligible unless they are measuring to within 5 to 10 dB of the analyzer noise floor, but the high accuracy of today's spectrum analyzers can make the added-noise error significant even for measurements with better signal/noise ratios.

The typical approach to handle these problems is to reduce the RBW of the analyzer to reduce its noise contribution, and to consider some type of averaging such as VBW reduction, trace averaging, or the use of an average detector to reduce measurement variance. RBW reduction is effective but can slow the measurement significantly, and does not solve the problem if the goal is to measure the signal's noise level. This is because reducing RBW will reduce the apparent noise level of the signal and the analyzer DANL together.

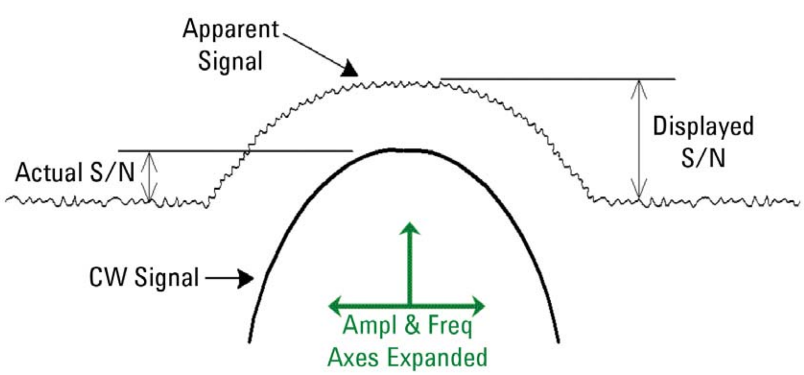


Figure 1. The measurement of a CW signal includes both the signal power and the portion of the analyzer's own noise present in the resolution bandwidth. When the measured signal is near the analyzer's noise floor both the amplitude of the signal and its apparent signal/noise ratio are affected.

Reducing attenuation can improve the SNR of the measurement, but attenuation at or near 0 dB can result in poorer source match (the input signal is connected more directly to the analyzer's first mixer, not a perfect 50 ohm device) and reduced amplitude accuracy. It can also endanger the analyzer's input mixer due to the possibility of damage from excess signal power, including transients.

Adding a preamp can improve SNR but may increase distortion products from the analyzer if large signals are present along with the small signal(s) to be measured. Distortion products from the preamp can be difficult to separate from those of the signal under test.

While lowering an analyzer's inherent noise floor through hardware design and component choices is obviously beneficial for dynamic range, there are practical limits, and another approach offers significant improvement. With sufficient processing and other technical innovations, the noise power in a signal analyzer can be modeled and subtracted from measurement results to reduce the effective noise level. In the Agilent PXA signal analyzer this operation is called Noise Floor Extension (NFE). The technique, its benefits, and practical use considerations are described in this application note.

Table of Contents

2. NFE and Noise Subtraction or Noise Correction

Generally speaking, if the noise power contribution of an analyzer can be accurately known, this power can be subtracted from various kinds of spectrum measurements. Examples include signal power or band power, ACPR, spurious, phase noise, harmonic and intermodulation distortion. Noise subtraction techniques do not improve the performance of vector analysis operations such as demodulation or time-domain displays of signals.

The noise power subtraction technique is described in detail in Section 7 *Subtracting the Noise* later in this application note. Knowledge of the noise subtraction technique itself is not necessary for its effective use; it is adequate to proceed with an understanding that the analyzer noise power is accurately modeled and then automatically subtracted in real time from spectrum results.

The specifics of the analyzer noise power modeling for the PXA are described in Section 6 *Modeling the Analyzer Noise Floor* later in this application note.

Agilent has been demonstrating noise subtraction capability for some time, using trace math in vector signal analyzers to remove analyzer noise from spectrum and band power measurements (similar trace math is available in the Agilent X-Series signal analyzers). This capability was effective, though somewhat inconvenient. It involved disconnecting the signal from the analyzer, measuring analyzer noise level with a large amount of averaging, reconnecting the signal, and using trace math to display a corrected result. It was necessary to re-measure the analyzer noise power every time the analyzer configuration (frequency center/span, attenuator/input range, resolution bandwidth) changed.

The situation improved somewhat with phase noise and ACPR measurement applications in the Agilent PSA and X-Series analyzers, where the analyzer would automatically measure its own noise level in each specific measurement configuration and perform the subtraction. This technique worked very well and is still the most accurate way of removing an analyzer's noise contribution. However it involves a measurement speed penalty to make the reference measurement and does not apply to general spectrum measurements unless the reference measurement is made.

The Agilent PXA analyzers dramatically improve this measurement technique for many measurement situations. Critical parameters which determine the analyzer's noise floor are measured when it is calibrated, and these parameters are used to fully model the analyzer's noise floor, including changes in analyzer configuration and operating conditions. The analyzer's noise contribution is then automatically subtracted from spectrum and power measurements. This process in the PXA is called Noise Floor Extension and is enabled with a keystroke in the Mode Setup menu. An example is shown in Figure 2.

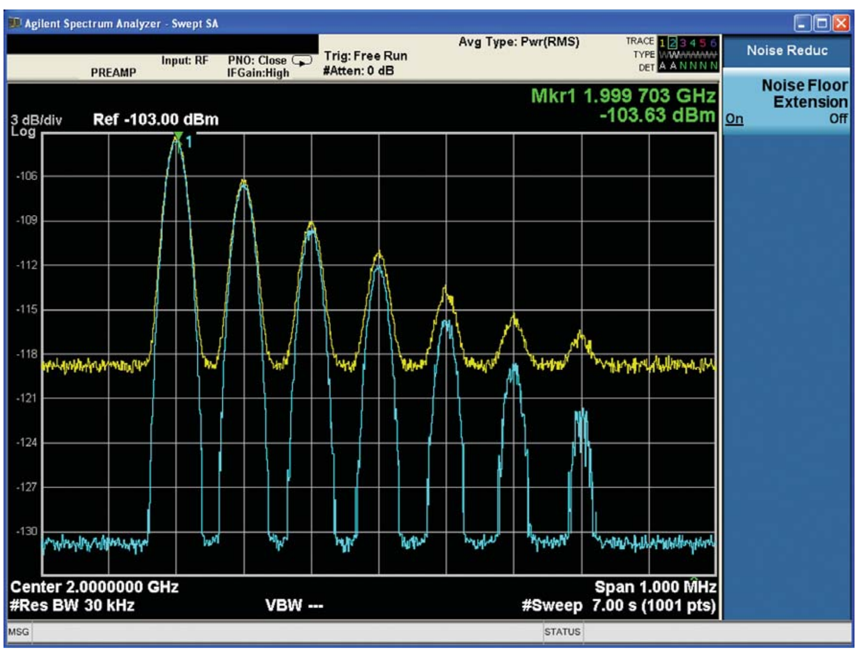


Figure 2. A signal with multiple tones of decreasing amplitudes (3 dB/tone) is measured near the analyzer's uncompensated noise floor, shown by the yellow trace. Using NFE in the PXA yields the more accurate trace in blue. Note that the error due to analyzer noise contribution is negligible for the first/highest tone, but approximately 3 dB for the 6th tone, where the tone amplitude is approximately the same as the analyzer's noise floor. This 10+ dB improvement in effective noise floor requires no user action beyond keystroke activation of NFE.

3. General Limits and Tradeoffs of NFE

NFE cannot remove all of the analyzer's noise contribution to measurements, since that contribution cannot be perfectly known. Indeed, in NFE operation the noise contribution of the analyzer is not quite as precisely known as, for example, when it is individually measured during noise subtraction operations of the PXA's phase noise and ACPR applications.

In addition NFE typically increases the variance of measurement results, when expressed in decibels, substantially due to its operation in subtracting similar power values. For optimum accuracy some type of averaging is required, and more averaging provides more accurate results. The PXA's average detector can provide a large amount of averaging in the optimum measurement time, as discussed later in this note.

4. Using NFE

In the Agilent PXA, the feature is enabled or disabled for spectrum analysis through Mode Setup→Noise Reduction. The factory default is for NFE to be disabled. The status of NFE is unchanged by the Mode Preset key. NFE does not have a significant impact on measurement throughput.

The effectiveness of NFE can be expressed in several ways. Average noise power in the display (DANL) is usually reduced by 10 to12 dB in the analyzer's low band (below 3.6 GHz) and about 8 dB in its high band (above 3.6 GHz). While the apparent noise level will be reduced, only the analyzer's noise power is being subtracted. Therefore the apparent power of signals in the display will be reduced if the analyzer's noise power is a significant part of their power, and not otherwise. Thus measurements of both discrete signals and the noise floor of signal sources connected to the PXA are more accurately measured with NFE enabled.

NFE works with all spectrum measurements regardless of RBW or VBW, and also works with any type of detector or averaging. However NFE is only effective when some type of smoothing or averaging is used with the trace.

Smoothing and averaging processes include one or a combination of the following:

- Narrow VBW (narrower than the selected RBW)
- The use of the average or peak detector with long sweep times
- Trace averaging.

In configurations where NFE is ineffective, it has no undesirable side effects on the measurement results.

4.1 Choosing the best detectors and averaging processes for each signal and measurement type

For a summary of these recommendations according to signal type please see Table 1.

This section will provide some general suggestions for choosing detectors and averaging to optimize the performance of NFE. Quantitative examples of the effectiveness of NFE for an example measurement of several signal types are discussed in Section 5 *NFE Effectiveness for Different Signal Types*. Scales and the bias of different detector types are described in more detail in Sections 8 and 9 of this note. More detail on detector and averaging choices, and on general techniques for measuring different signal types is provided in *Agilent Application Note 150 Spectrum Analysis Basics*, literature number 5952-0292.

Because the NFE process increases the variance of the post-NFE results, NFE works best with large, or even very large, amounts of smoothing.

In particular, since NFE works individually on each display point or "bucket," the best accuracy is achieved *when extensive smoothing or averaging is done on each point prior to trace averaging*. Fortunately, measurement and processing operations are available in the PXA to provide large amounts of this kind of trace smoothing very rapidly.

Where practical, the most effective smoothing is obtained by using the average detector, with the Average Type set to Power, and choosing a longer sweep time than the autocoupled value. The average detector calculates the average of all IF amplitude samples made during the duration of a display bucket, so that the maximum amount of data is extracted during the measurement sweep.

Thus, for a given total measurement time and when using the average detector, results are better with long sweep times and fewer (or even no) trace averages. If using the sample detector instead, the VBW filter should be used for smoothing, and set to a narrow value (significantly narrower than the RBW) and less trace averaging should be used. The alternative of a wider VBW filter with more trace averaging is less efficient at reducing measurement variance.

For a given frequency span and sweep time, the length of a display bucket (in time, proportional to the number of measurement samples) is inversely proportional to the number of display points. Therefore the amount of smoothing for each display point can be increased by using a longer sweep time or by reducing the number of display points. The number of display points or buckets is controlled through the points parameter, set by pressing Sweep/Control and Points.

4.1.1 CW signals

While the average detector is most effective at reducing variance and optimizing the performance of NFE, it is impractical for some CW measurements. When the selected RBW is not significantly wider than a display bucket, the peak of a CW signal will not be accurately represented due to the averaging of measured values across the display bucket. This effect is sometimes called scalloping error, and applies to the combination of comparatively narrow RBWs and the average or sample detectors.

Instead, when the RBW is narrower than or similar in width to a display bucket, the "normal" detector (an intelligent combination of the peak and negative peak detectors) or a peak detector should be used. The peak detector is a particularly good choice when making measurements against a maximum limit. When these detectors are used the averaging should be performed with a narrow VBW setting, and trace averaging can be used if further variance reduction is desired.

It is important to understand, however, that real-world CW signals will have some amount of residual AM, FM or phase noise, and may therefore behave in a somewhat noise-like fashion. If residual AM, FM or phase noise spreads the signal beyond the selected RBW a wider RBW should be used. With wider RBWs NFE may be more practical in improving dynamic range and this situation would suggest the combination of a wider RBW and the average detector.

For any situation where a signal is spread beyond the selected RBW consider using the "Band/Interval Power" marker function to integrate the total signal power and provide the most accurate signal power result. Band power markers are compatible with NFE.

4.1.2 Noise and noise-like signals (including digital modulation)

As described in section Section 5 *NFE Effectiveness for Different Signal Types*, NFE works very well with noise-like signals, where some degree of averaging is already necessary for accurate measurements. This application note also discusses why the separation of the signal from the analyzer noise floor is not dependent on RBW setting.

For noise-like signals and the analyzer or system noise that may complicate their measurement, the average detector (operating on the autocoupled default power scale) is the most accurate and efficient choice. Indeed, except for the benefit of more frequent display updates, the most efficient averaging or smoothing is accomplished by using the average detector with extended sweep times, and no trace averaging. The sweep time can simply be extended until the desired degree of variance reduction is achieved.

Where display updates for interim results are desired, trace averaging can be used in combination with the average detector. Sweep time setting and the number of trace averages can be tailored to the accuracy, measurement variance, and update rate needs of the measurement.

4.1.3 Pulsed-RF signals

As described in section Section 5 *NFE Effectiveness for Different Signal Types*, NFE provides a dramatic improvement for pulsed-RF signals. In measuring these signals it is desirable for each display point to represent the peak of a large number of measured pulse responses. This provides a great degree of smoothing and enhances measurement accuracy.

As described in that section of this note, the separation of the signal from the analyzer noise floor improves with wider RBW setting, the opposite of the situation when measuring CW signals. Wider RBW settings, where the impulse response of the RBW filter is matched to the signal under test, allow the peak amplitude of the signal to be captured by the peak detector, the preferred one for these measurements. A wide VBW setting, similar to the RBW or wider, is also important to ensure accurate measurement of peak amplitude.

As with noise-like signals, the most efficient averaging or smoothing is accomplished with an extended sweep time length instead of trace averaging, though both can be used together.

Table 1: Most efficient detectors and averaging for use with NFE

Signal type	Detector	Averaging or smoothing type[1]	Averaging scale
CW, narrow RBW[3]	Normal or peak	Narrow VBW, Trace[2]	Log-power (video)
CW, wide RBW[3]	Average	Long sweep time, Trace[2]	Power (RMS)
Noise-like or digitally modulated	Average	Long sweep time, Trace[2]	Power (RMS)
Pulsed-RF	Peak	Long sweep time, Max-Hold Trace[2]	Log-power (video) or power (RMS)[4]

1. *Averaging/smoothing types are listed in decreasing order of effectiveness.*
2. *Trace averaging is a less efficient smoothing technique (it reduces trace variability more slowly) but it has the advantage of providing trace updates more quickly when long sweep times (including those due to narrow VBW) would otherwise be associated with a large amount of averaging. Narrow VBWs and long sweep times, however, give the user immediate visual feedback on the amount of trace smoothing they provide.*
3. *For the purposes of this table "narrow RBW" refers to cases where a display bucket or point is significantly wider (in frequency) than the selected RBW. This situation can cause incorrect amplitude readings, sometimes known as "scalloping error."*
4. *For measurements of pulse envelope using the analyzer in a zero-span mode, the voltage average is normally used.*

Average type is automatically set by the analyzer, according to the detector chosen. To manually set the average type press Meas Setup→Average Type and choose from the available types: Log-Pwr (video), Pwr (RMS), and Voltage.

4.2 Measurements near the theoretical kTB noise floor

NFE operations are based on manufacturing or periodic calibrations using a 50 Ω resistor connected to the input as a noise power reference. In low band operations (below 3.6 GHz) with the preamplifier enabled and attenuation set to 0 dB, NFE operation in the PXA can frequently subtract enough of the analyzer's noise that the remaining power is at or below the kTB noise floor (–174 dBm/Hz in 50 Ω at room temp).

Thus the kTB noise floor should not be seen as an impenetrable barrier through which no smaller signals can be seen. Small signals, even those below kTB, add to the analyzer's own noise floor and when the analyzer noise (including the 50 Ω kTB portion) is removed these signals become measurable. Such measurements are valid (and useful) for some situations but not all.

In particular, NFE improves the measurement of signals which are attenuated to very low levels by splitters and other losses before they reach the analyzer input. See Figure 3 for an example.

NFE improves measurements when the measurement error is expressed in power terms (watts, not dB or dBm). However when errors are measured in dB, very small errors in power terms can translate to much larger errors in terms of negative dB. Thus the use of NFE can produce larger dB errors for extremely small signals and tolerances for these extremely small signals may be better evaluated in linear power terms.

An example of a sub-kTB measurement is shown in Figure 3. Note the marker: The noise density in this actual measurement was about 3 dB below the theoretical noise of –174 dBm/Hz at room temperature!*

* *What is actually being measured is that part of the signal source power that is in excess of the theoretical noise in a 50 Ω resistor. That is why it can read below kTB.*

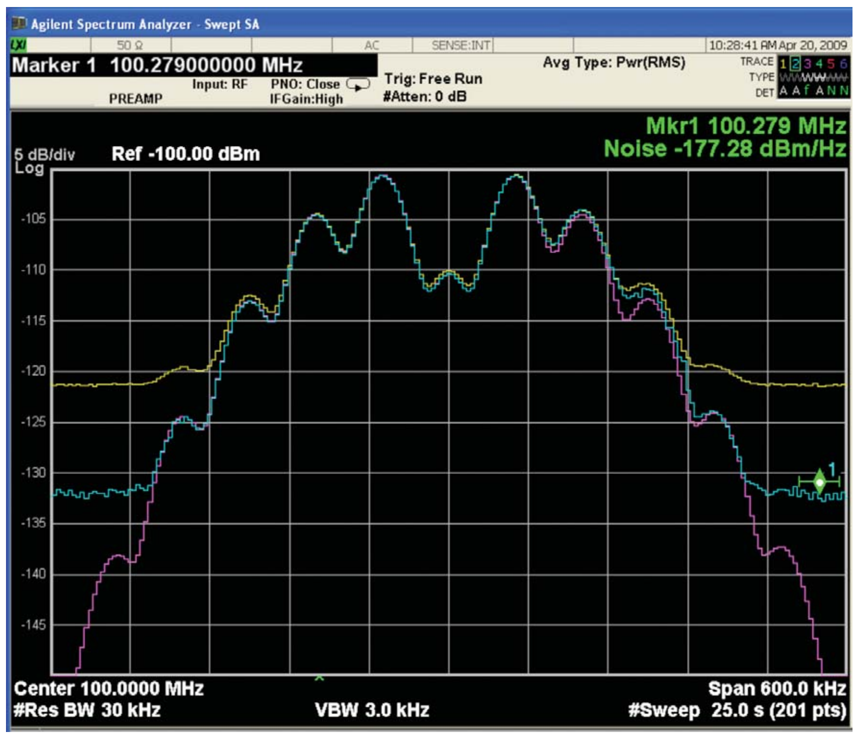


Figure 3. With very large amounts of averaging, very low signal levels can be measured. This display shows an upper trace without NFE and a middle trace with NFE. Signal levels below the theoretical noise of the impedance of the signal source can be seen. The third trace shows the signal generator level measured with a 40 dB higher level, then offset for comparison. Note the tradeoffs exposed in this measurement. The number of points was reduced to 201, the RBW widened to 30 kHz, and the sweep time increased to 25 s to keep the NFE trace variations modest. With 10 dB improvement in the noise floor, the NFE trace will always have a ten times higher standard deviation than in the top trace.

5. NFE Effectiveness for Different Signal Types

5.1 Amplitude envelope versus time

One way to consider signal types is in their statistical distribution of amplitude envelope versus time. In this view, signals can be CW-like, noise-like, impulsive, or a combination of these.

From a spectrum-analyzer perspective, these signal types strongly influence the optimum RBW for signal measurement. Consider Figure 4 which shows qualitatively the signal-to-noise behavior versus RBW of these three signal types.

We can think of the RBW filter as giving the best S:N ratio when it is matched to the signal. When the signal spectrum is very narrow (CW), the narrowest RBW works best. When the signal is a short pulse in the time domain, an RBW with a short impulse response (wide bandwidth) works best. When the signal is noise-like, all RBWs are equally well matched to the signal such that changing the RBW does not improve the ability of the filter to separate analyzer noise from the input signal.

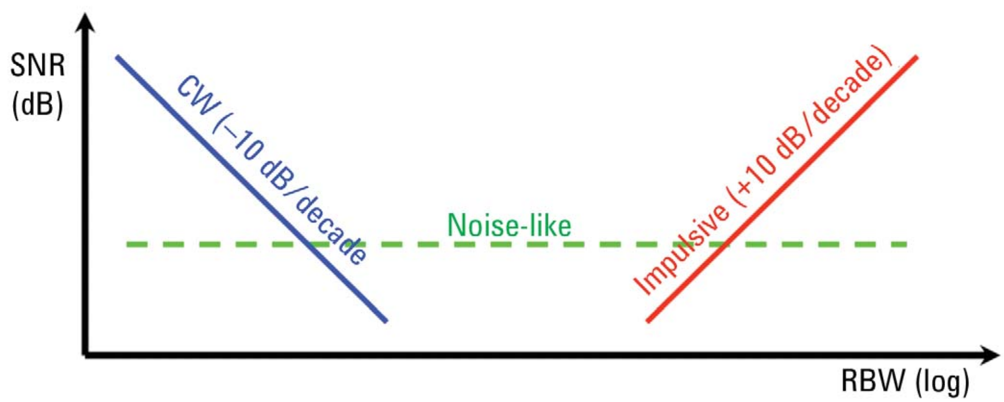


Figure 4. The signal-to-noise ratio varies differently with RBW for the three kinds of signals. Impulsive signals work best with the widest RBWs, CW signals with the narrowest RBWs, and noise-like signals work equally well with all RBWs.

5.2 CW signals: modest improvement

As explained in Section 7 *Subtracting the Noise*, when examining signals below the uncompensated noise floor P_{obsN} the variance of the measurement gets greatly multiplied. For example, for a 5 dB reduction in noise floor, we have to average ten times as long to get the same standard deviations (when expressed in decibels) in our results as we had without NFE. Let's compare this with swept analysis. If we reduce the RBW by a factor of $\sqrt{10}$, we also get a 5 dB reduction in noise floor and we also have to spend ten times as long on our sweep. Thus, in some ways, NFE is only as helpful as is a reduction in the minimum RBW, for the case of CW signals.

This is not a fully fair analysis, though, because perfect CW signals do not exist. If a signal has residual FM, the RBW cannot be reduced too far without that FM causing amplitude uncertainty. And if a signal has residual AM, some averaging is already desirable, thereby allowing improvement with NFE.

Figure 5 shows the effect of NFE on the 95% coverage interval of amplitude accuracy with a lot of averaging. Log averaging is used because, without NFE, it reduces the mean error in measuring CW signals in the presence of noise. With NFE, power averaging is used because the mean error is zero with NFE and power averaging gives lower variance. As you can see, the signal level that can be measured to a ±2 dB tolerance is about 3.5 dB lower with NFE. More averaging would allow more improvement; see Section 4 *Measurements Near the Theoretical Noise Floor* for an extreme example.

5.3 Noise-like signals: dramatic improvement

NFE works very well with noise-like signals, such as digital communication signals. These signals, being noise-like, already require substantial averaging to reduce the variance of the result. Figure 6 shows how well this can work. You can see that the input signal can be more than 9 dB lower with NFE than without while still assuring that the 95% coverage interval stays within the ±1 dB tolerance region. (This figure is based on a 95th percentile accuracy of the NFE model sufficient to reduce the noise levels by 8 dB, which is a conservative estimate of low-band performance.)

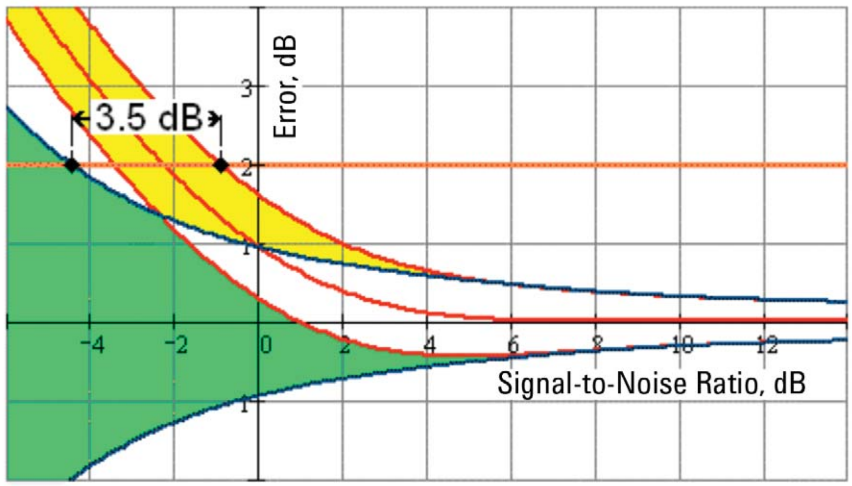


Figure 5. CW signal measured with averaging. The upper three curves show the mean and limits of the 95% coverage interval without NFE. The lower two curves show the 95% coverage interval with NFE (the mean curve is coincident with the axis). You can see that a S:N ratio of better than –0.9 dB is required without NFE to keep the measurement error below 2 dB. With NFE, signals 3.5 dB lower (a S:N ratio of –4.4 dB or better) can stay within with a 2 dB window.

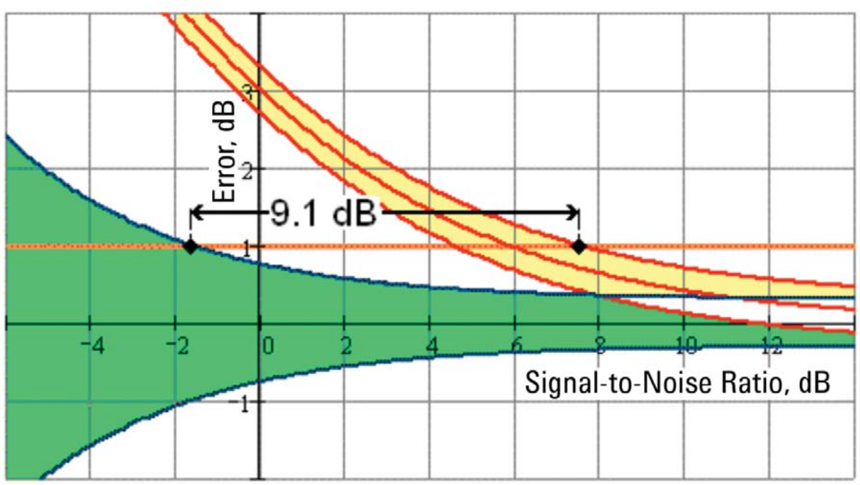


Figure 6. Noise-like signal measured with and without NFE. The upper three curves show the mean and 95% coverage interval without NFE. With NFE, the mean error is zero and the 95% coverage interval is shown by the lower curves. You can see that a signal-to-noise ratio of 7.5 dB or more is necessary for the high end of the 95% coverage interval to give less than 1 dB error without NFE. With NFE, a signal-to-noise ratio of –1.6 dB or better keeps errors within the ±1 dB range. Thus, NFE is as effective as a 9.1 dB improvement in noise floor.

5.4 Pulsed-RF signals: big improvements

NFE can be quite effective for pulsed-RF signals. Consider the peak detector. A combination of Max-Hold trace processing and slow sweep times (slow enough that trace elements have durations long compared to the period of the pulsed RF) can often result in each trace element being the highest of 10, 100 or even 1000 pulsed signal responses combined with noise. The variance of the highest of a large number of measurements is much lower than that variance of pure noise or noise measured with just a few pulses. Low variance allows for high effectiveness of NFE. Figure 7 shows how an improvement on the order of 10 dB can be expected in the required signal-to-noise ratio for a 3 dB worst-case error in measuring pulsed-RF signals.

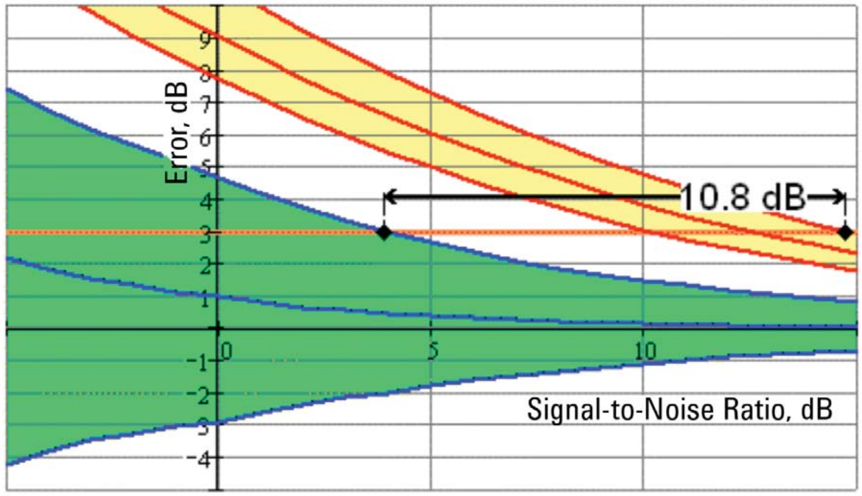


Figure 7. Pulsed-RF signals can be measured with any combination of Max-Hold trace processing and peak detection. Shown here is the 95% coverage interval with and without NFE for a signal with 100 peaks in each result. Consider a 3 dB maximum error. Without NFE, the signal-to-noise ratio needs to be 14.8 dB to keep the maximum error below +3 dB. With NFE, a signal-to-noise ratio of 4.0 dB is sufficient to keep the error within the range of ±3 dB, an improvement of 10.8 dB. Another way to look at this situation is to observe that, with 5 dB SNR, the 95th percentile error declines from +7.3 dB to +2.8 dB with NFE.

6. Modeling the Analyzer Noise Floor

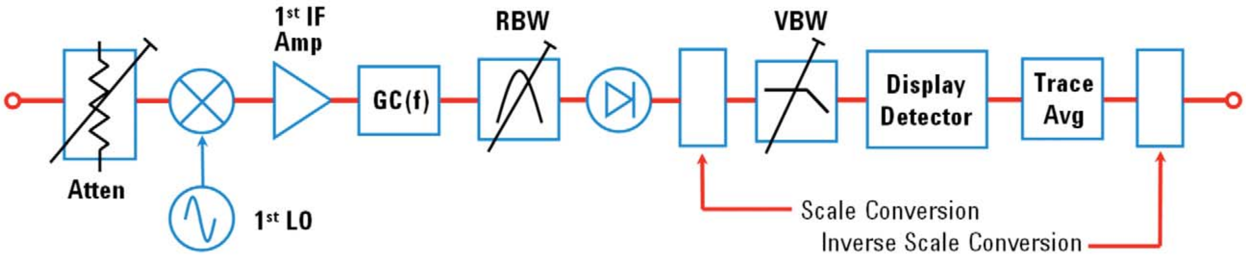


Figure 8. Low band measurements are made by upconverting the signal, then correcting for frequency response flatness with the block labeled GC(f). This block diagram is particularly easy to model for noise.

The first step in subtracting the noise contributed by the analyzer is to accurately characterize it over the operating range of the measurements. This involves modeling the noise floor and combining the model with measurements of individual analyzers to accurately estimate their noise floor.

The noise level of a spectrum analyzer varies as a function of many different parameters. A reasonably complete list of these parameters includes: the resolution bandwidth (RBW), the input attenuation, the tuned frequency (including the amplitude correction and mixing band associated with that frequency), the display detector and the averaging scale. We will now examine summarizing the noise contributions in a spectrum analyzer in its low-band, preamplifier, and high-band paths.

6.1 Low band: the passive heterodyned section

The lowest frequencies (such as DC to 3.6 GHz) are measured with a block diagram as shown in Figure 8.

The noise added by the spectrum analyzer, reflected back to the input terminal, obviously increases proportionally to the input attenuator. It also increases proportionally to the noise bandwidth of the RBW filters. Especially of interest to us is the behavior of the noise relative to the tuned frequency.

In the block diagram, you will notice the Gain Compensation block, GC(f), which compensates for frequency-dependent losses in the analyzer front end. These losses all occur before the output of the first mixer. Because all frequencies in a swept spectrum analyzer are measured at the same IF frequency, signal gain after the first mixer does not affect frequency response nor cause frequency-dependent noise levels.

Therefore, this section can be modeled for all low-band frequencies as having just two frequency-independent noise sources, e1 and e2, as shown in Figure 9.

GC(f) is set to the inverse (the negative in decibels) of the Loss(f), in order that the overall conversion gain be calibrated to be flat versus frequency.

This means that the second noise source, e2, is equivalent to an input noise that is independent of center frequency. The e1 noise source reflects to an equivalent input noise through the inverse of Loss(f). Because Loss(f) is very well known due to the excellent calibration of a typical spectrum analyzer (the standard deviation of error here is on the order of 0.06 dB), the noise can be characterized to excellent accuracy with just the two parameters, e1 and e2.

Agilent's experience shows that the noise models can be accurate enough to typically model more than 90% of the noise power, thus allowing typically better than 10 dB reduction in the effective (post-compensated, highly averaged) noise floor.

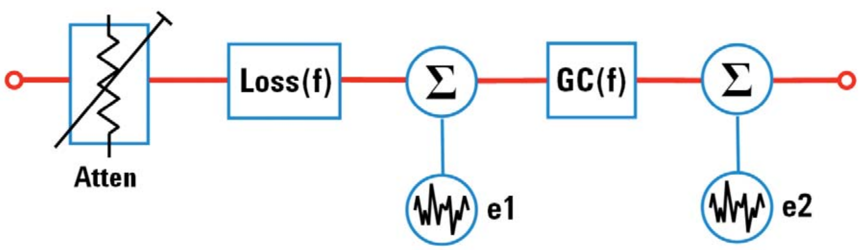


Figure 9. A low-band spectrum analyzer front end can be easily modeled for all input frequencies as having just two frequency-independent noise sources.

6.2 Preamplifier noise floor

Preamplifiers are now often built into spectrum analyzers. Ideally, their noise floor is constant versus frequency, but they are not ideal. A more accurate model would have a linear relationship as shown in Figure 10.

In the PXA measurements are made of the noise floor at various frequencies (as is done in verifying conformance with specifications) and fit these to a straight line model using a linear regression.

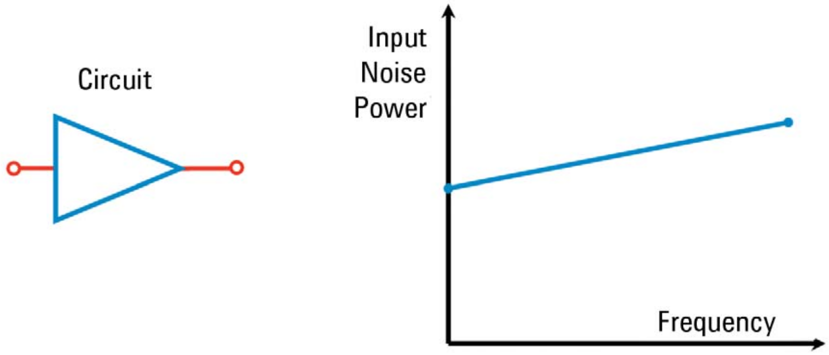


Figure 10. The noise floor of a preamplifier can be modeled as increasing linearly with frequency.

6.3 High band section

The "high band" frequency range in a spectrum analyzer has a down-conversion stage with the image rejected by a YIG- (yttrium-iron-garnet) tuned filter (YTF) as shown in Figure 11.

The figure shows both the YTF and the circuits that cause the "banding" effects. We will discuss both.

The YTF is a very high Q filter that prevents image responses from being significant by having a loss of more than 80 dB at a spacing of twice the IF frequency (thus 645 MHz). But its stability is poor, due to its high Q, requiring some of the highest frequency ranges to have an amplitude uncertainty about an order of magnitude higher than in low band. Even so, although the instability causes an amplitude accuracy problem, it is not a direct influence on the noise modeling accuracy.

The high band is typically made up of four numbered frequency ranges, bands 1 to 4. Band 1, for example, covers 3.6 to 8.4 GHz using the unmultiplied first LO and a mixer optimized for direct mixing. All four combinations of LO (fundamental or doubled) and mixer (optimized for fundamental or second-harmonic mixing) are used to create these four bands with optimum performance.

The banding would not be important to our discussion except for the two kinds of preamplification not shown in the block diagram.

There is a gain stage between the YTF and the mixers, at the location labeled "B" in the figure. When we discussed low band, we saw that gain stages at IF frequencies have noise levels that are independent of the signal frequency. This gain stage operates directly at the signal frequency. Because of this, the heterodyned two-parameter model that worked so well in low band is not a good model for high band. Yet, there are so many frequency-dependent losses that a linearly-compensated-versus-frequency model (the preamp model) does not adequately model the noise.

Instead, each of the four bands of high band is characterized by a combination of the low-band two-parameter model and the preamp 2-parameter model. This is imperfect but still effective. It uses a 4-parameter regression. Running the regression separately for each band allows good conformance with the data.

Additionally, there is also an optional preamp before the YTF, at the location labeled "A" in the figure. This, too, is well modeled with yet another 4-parameter model, separately in each band.

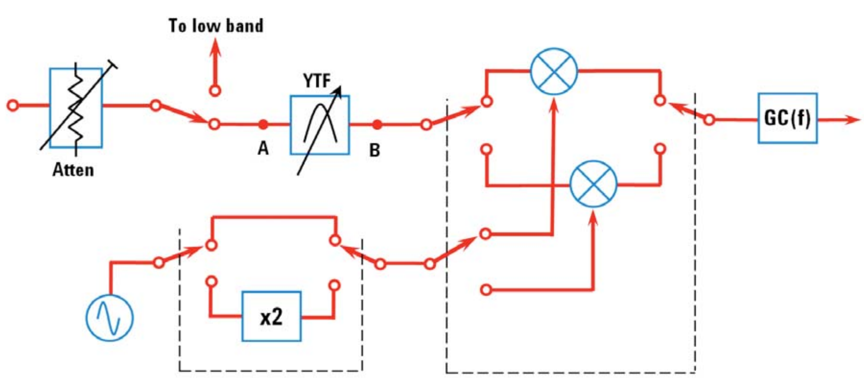


Figure 11. The block diagram of high band analysis includes the low-stability YIG-tuned filter, as well as an LO doubler and separate mixers optimized for fundamental and second-harmonic mixing.

7. Subtracting the Noise

Now that we have determined the noise contributions of the analyzer, we will discuss the mathematical means of subtracting it and thus providing the best dynamic range for measuring the input signal.

The noise of the analyzer adds incoherently to the noise or any other signal type that constitutes the signal to be measured at the analyzer input.

In the simplest case, the input signal is noise-like and the analyzer response is proportional to the total power. Mathematically, we could say:

$$P_{obsS+N} = P_{obsN} + P_S$$

The observed power of the signal plus the analyzer noise is the sum of the observed noise of the analyzer alone plus the power of the input signal. Thus, our predicted input power is found simply from the solution of the equation:

$$P_S = P_{obsS+N} - P_{obsN}$$

Graphically, using a linear power scale (note that this is not a linear-in-voltage scale, nor a decibel scale) we see the relationship in Figure 12.

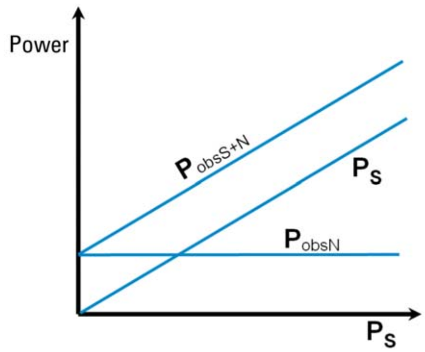


Figure 12. The observed signal-plus-noise power is simply the sum of the analyzer noise power and the signal power.

If we plot this on a decibel scale (Figure 13), it will help our visualization.

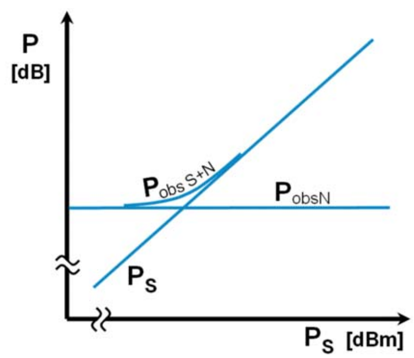


Figure 13. The sum of the analyzer noise power and the signal power shows two asymptotes on a log-log scale.

Solving for P_S we see the results in Figure 14.

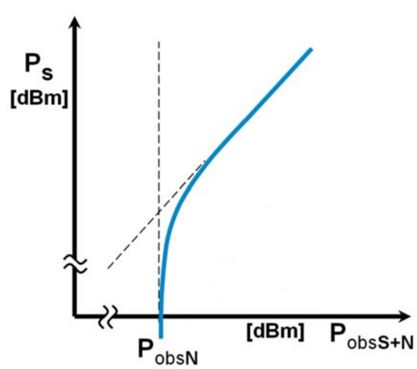


Figure 14. The computed input power has a strong dependence on the measured sum of the signal and analyzer noise when the signal is small compared to the analyzer noise. It even has a region (observations below the observed noise level) for which the computation fails.

This graph shows us a lot. First, we see that there is no valid expressed-in-decibels solution for P_S when the observed sum of signal and analyzer power is less than the observed noise-only power. The linear mathematics shows the calculated power to be negative in this case. Negative power is neither physically reasonable nor describable in decibels. (Though this situation is not physically reasonable, due to the variance of noise measurements, it does happen. Our adaptation to this problem is to constrain our computed P_S to be never lower than 12 dB below the measured sum.)

The second learning from the graph is that the slope gets very high as P_{obsS+N} approaches P_{obsN}. What this means is that, as P_S gets small compared to P_{obsN} the variance of our measurement gets highly multiplied. This is a fundamental limitation on the usefulness of noise floor extension.

This straightforward case we just discussed used power detection and an unbiased detector. NFE operation on other scales and detectors is discussed in the next section, *Log and Voltage Scales*.

8. Log and Voltage Scales

To help in understanding the effect the log and voltage scales, it is useful to discuss the averaging processes in spectrum analyzers. There are four such processes in most analyzers. One is the trace averaging process. A second is the video bandwidth filter (VBW). Third: most modern analyzers have a detector that averages the observed level for the duration of a measurement cell, also sometimes called a trace element, point, pixel or bucket. Fourth: noise markers average across a subset of the displayed trace. In the PXA, other Agilent X-Series analyzers, and the Agilent PSA spectrum analyzer, all four of these processes are locked together to one of three scales (power, voltage or log) according to the setting of the "Average Type" key. Through the early 1990s, swept spectrum analyzers were only capable of averaging on the log and lin (linear voltage) scales, so power (r.m.s. voltage) averaging is not familiar to all users.

The straightforward power scale has been discussed previously in this note. Now we will discuss the other scales.

When the averaging scale is log, the response to noise is –2.506 dB compared to the ideal power response. This is because log averaging measures the log of the power (a nonlinear operation) and averages that. The ideal measurement of the power (the heating value) is to average the power, and then express it in decibels by taking the logarithm. The former average-of-the-log result will not be the same as the latter log-of-the-average result because these operations are not mathematically exchangeable. The average-of-the-log result overemphasizes near-zero power events by computing very large negative results for these events.

If we measure P_{obsS+N} with log averaging, we can account for the effect of log averaging on our result and on our P_{obsN} so we can still achieve noise floor extension. This is not the preferred way to make the measurement, though, because we must average for 60% longer to achieve the same variance as with power averaging.

When the average scale is linear (in volts), the response is –1.049 dB compared to the ideal power response. Again, for convenience and completeness, Noise Floor Extension can be accomplished using this scale, but the measurement time required to achieve the same variance increases.

9. Biased Detectors

The detection process discussed so far has been unbiased with respect to signal statistics, as is characteristic of sample and average detectors. Now we will discuss other detection types and the impact NFE has for each. Another commonly used detector is the peak detector. It saves the highest signal level found in the duration of a bucket. The results of peak detection will not be proportional to the total power unless the signal statistics are noise-like. For example, consider carrier-wave (CW) signals. If the signal is CW-like, the measured level of the sum of the input CW signal and the analyzer noise depends on the average type. A full set of equations models the effect of different detectors and average types to optimally extract the signal level from the P_{obsS+N} and P_{obsN} assuming a CW-like signal. This method of NFE is not quite as effective and accurate as using the power scale and an unbiased detector, but it still significantly extends the dynamic range. It can be quite effective for pulsed-RF signals.

The negative peak detector is also less than ideal but NFE can still achieve some improvement. The same is also true for the "Normal" detector.

10. Summary

As discussed, Agilent's PXA signal analyzer with Noise Floor Extension can effectively process and subtract out the noise power from measurement results to reduce the effective noise level. The NFE's benefits and practical use considerations were also described.

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