Detector Selection for Spectrum analyzer Measurements

There are many different types of detectors in use in signal analysis systems. Each has a unique definition as well as differing advantages and disadvantages. And choosing the right one is critical to obtaining valid data.

Note that the detector types discussed here are different from the detectors that convert the IF signal to a video signal. Even though the envelope detector is central to the operation of a spectrum analyzer, it gets very little notice from users because it has no controls. The “display detector” or detector types must be set correctly to accurately measure continuous wave (CW), noise, and noise-like signals. Figure 1 represents the block diagram of a traditional swept spectrum analyzer with a digital display.

The Peak Detector

Figure 3 demonstrates a circumstance where the width of the resolution bandwidth result is narrow compared to a bucket width. An example might be a spectrum analyzer with a maximum resolution bandwidth (RBW) of 3 MHz, and a span of 20 GHz, with 600 bucket intervals in the span. Each bucket would be 33 MHz wide. The –60 dB width of the RBW might be 18 MHz. If the signal peak is centered in the bucket, samples taken at the bucket boundaries might completely miss the signal. One advantage of using the peak detector is that it finds signals even when the span:RBW ratio is high. This is especially true in the wide span case discussed in this article, as well as in electronic spectrum surveillance applications.

The Sample Detector

The sample detector is a simple detector. One disadvantage is the inaccurate capture of the CW amplitudes mentioned previously (see the sidebar). A second disadvantage is that the inherent location of the highest bucket result is different by one-half bucket on the average from the location displayed by the peak detector. A CW signal anywhere in the bucket interval is captured at the end of the bucket by the peak detector. With the sample detector, a CW peak in the first half of the bucket will cause a higher response in the previous bucket than the current bucket. Because the peak detector is the standard detector for accuracy purposes, the relative location of the highest amplitude bucket when using sample detection represents a one-half bucket error term in the specification of frequency readout accuracy. This error was negligible in older spectrum analyzers without fully frequency-synthesized operation. But in new-generation analyzers, the frequency readout accuracy can be as low as 0.25 percent of span (versus 5 percent for previous generations). Thus, the half-bucket error is significant. New analyzers actually shift the sweep timing by

Peak, Pit and Sample

Figure 2 demonstrates a noise-like signal envelope versus time. The vertical marks show the boundaries of a measurement cell. This time duration is often informally referred to as “bucket,” as is the result measured for that measurement cell. Other terms that may be used in place of bucket are “points” and “pixels.” Within the time of a bucket, the peak detector stores the largest signal for subsequent A/D conversion. The negative peak (pit) detector stores the lowest amplitude signal. The sample detector merely stores the final amplitude.

The actions of these three detectors are demonstrated again in figure 3. In this example, the video signal represents sweeping through a CW tone. Let’s examine these three detectors, and others, in detail.

Figure 1. A swept spectrum analyzer converts the continuous video signal into samples for A/D conversion using "detect or mode" hardware
0.5 bucket to overcome the frequency accuracy impact of the sample detector.

The primary uses of the sample detector are in the measurement of noise and noise-like signals, and near-noise CW amplitudes. The peak detector emphasizes noise because it captures the peak excursions. This behavior makes measuring a low-level CW signal error-prone. But the sample detector does not peak-bias bucket results, improving signal-to-noise ratio. Therefore, when averaged, the results of sample detection are excellent in measuring small CW signals. For a detailed explanation of measuring small CW signals, see reference note 1.

Because of its usefulness in measuring noise, the sample detector is usually used in “noise marker” applications (refer to the sidebar).

Similarly, the measurement of channel power (CP) and adjacent-channel power (ACP) requires a detector type that gives results unbiased by peak detection. For analyzers without averaging detectors, sample detection is the best choice.

The Negative Peak Detector

While the negative peak detector is available in almost all spectrum analyzers, it is rarely used. It is mostly use for comparing peak and negative peak results in electromagnetic compatibility (EMC) applications. This allows the user to differentiate CW from impulsive signals.

Signal-and-noise Detectors

Detector types are useful because there is often more information in the continuous video signal than can be displayed with a fixed number of display locations. Analyzers used in the era before digital displays were effective in displaying signal peaks. These analyzers represented noise as gradations of display intensity. They depended on the statistics of signal-amplitude distribution. For these analyzers, the difference between the CW- and noise-like signals was immediately apparent.

There are a number of manufacturer-specific approaches to achieve a similar appearance. Referred to by names such as “normal” and “auto peak,” they show the peak-to-peak excursions of the amplitude envelope of a signal to give noise signals an apparent vertical width, while CW signals show as a single-valued trace across the screen.

Because these detectors are complex to implement and unnecessary for precision measurements, they are used only in the high-performance end of the product line of spectrum analyzer manufacturers (see reference note 2).

Averaging Detectors

The latest generations of spectrum analyzers have various implementation methods of averaging detection. In an averaging detector, the amplitude of the signal envelope is averaged during the time (and frequency) interval of a bucket.

The primary application of average detection is in CP and ACP measurements. These measurements involve summing power across a range of analyzer frequency buckets.

The average detector allows an improvement over using sample detection for the summation. It changes channel power measurements from being a summation over a range of buckets into an integration over the time interval representing a range of frequencies in a swept analyzer. In a fast Fourier transform (FFT) analyzer, the summation used for channel power measurements changes from being a summation over display buckets to being a summation over FFT bins. In both swept and FFT cases, the integration captures all the power information available, rather than just that which is sampled by the sample detector. As a result, the average detector has a lower variance result for the same measurement time. In swept analysis, it also allows the convenience of reducing variance simply by extending the sweep time.

The scale on which the averaging occurs is an important part of the measurement. Some spectrum analyzers will refer to the averaging detector as a root-mean-square (RMS) detector when it averages power. These same analyzers have an average detector. The average detector averages the voltage envelope of the signal. Others have an average detector and a separate control to select the averaging scale. All the averaging processes work on the same scale, including power (RMS voltage), voltage (envelope) and log (decibels). The averaging processes that apply are the average detector plus three others: trace averaging, VBW filtering, and noise marker averaging.

EMC Detectors

Receivers for characterizing devices for electromagnetic compatibility (EMC) use quasi-peak detectors (QPD) and average detection. These specialized detectors are not used for spectrum analysis, and are beyond the scope of this article. A few spectrum analyzers implement these detectors for EMC measurements. As a result, there is a terminology conflict between the average detector discussed previously and the average detection for EMC applications. These detectors are completely different and can potentially be confused.

FFTs and Detector Types

It has been discussed how detector types allow for the conversion of continuous-amplitude versus frequency information into an array of digitized results. FFT analysis can have the same detector relationships even though there is no such continuous signal as a starting point.

Just as detector types allowed any swept video signal to be converted into an array of trace buckets, so too can detector types be used to convert any
Noise Markers

The "noise marker" function is useful for measuring the power spectral density (PSD) of noise-like signals. When activated, the bucket amplitudes near the marker location (typically 5 percent of the displayed span) are averaged. The PSD is estimated from this average by normalizing to a 1 Hz ideal bandwidth. The normalization is based on the predicted noise power bandwidth of the RBW filter and the known response of the averaging process to noise-like signals.

Typically, the analyzer uses a log scale, which is known to under-respond by 2.51 dB to noise-like signals on average. The averaging that occurs can be due to the noise marker processing itself, VBW filtering, or trace averaging. Noise measurements made on a power scale are faster than those taken on a log scale.

Under some rare circumstances, such as rotating media noise measurements, the peak detector is used for noise measurements. Some analyzers can make noise measurements in peak, negative peak and normal detector modes, in addition to the traditional sample detector and the superior average detector. They also can make the computation on log, linear and power scales. The autocoupled combination of average detector and power scale is the fastest.

Scallop Error in FFTs and Sample Detection

In figure A, the same video signal is shown with three different relationships between the time of the peak of the video signal and the time of the samples. Signal one reaches its peak exactly at the sample instant. In this case, the largest sampled amplitude is the same one that would be read by a peak detector. But as the signal moves to the right (signals 2 and 3), the highest bucket result becomes lower in amplitude. The worst case is signal three, with its peak midway between samples. As the signal moves further to the right, the highest bucket result moves to the next bucket and starts to rise in amplitude.

Figure B is a graph of the highest sample amplitude versus the signal frequency. It repeats with a period of the frequency width of a bucket. This is a scallop shape. Scallop error is the difference between the highest sample result and the peak result.

The term "scalloping error" is not commonly used to describe the sample detector. It is a common term in FFT spectrum analysis. FFT computation results are just samples of a continuous spectrum. Figure B applies directly to FFT analysis, except that the period of the scallop is one FFT bin instead of one bucket.

Designers of FFT processing choose a "windowing" operation partly to control the scalloping error of their analysis. They often trade off the passband width (making for a wider passband, and thus less frequency resolution) to minimize scalloping error. But in a hybrid FFT/swept analyzer with detector types, the peak detector eliminates scalloping error. The windowing function, which affects the shape of the RBW filter in FFT analysis, can be chosen for the best tradeoff between selectivity and speed.

For Gaussian-shaped RBW filters, the maximum scalloping error depends on the RBW, the span, and the number of buckets in the display. The maximum scalloping error is:

\[ E_{\text{max}} = 3.01 \text{ dB} \left( \frac{\text{span}}{\text{RBW} (N_{\text{buck}} - 1)} \right)^2 \]

One typical analyzer will have a span:RBW ratio autocoupled to 106:1, and 601 buckets, giving a maximum scalloping error of 0.09 dB with the sample detector.

The average detector also has a response variation with frequency with a scallop shape. Unlike the sample detector, its minimum error is not zero. This is because averaging across the top of an RBW shape cannot give a response as high as the peak. The average detector response versus frequency varies from 0.33 to 1.33 of the \( E_{\text{max}} \) evaluated above. This case demonstrates why the average detector is not the preferred detector for CW signals. The scalloping error of the average detector is only an error in peak response, not in total power. Total power response measurements, such as channel power, are the intended use of the average detector.
FFT bin results into an array of trace buckets. Thus, detector types allow swept and FFT analysis to behave nearly identically.

**Optimum and Automatic Selection of Detector Types**

This article has discussed the advantages and disadvantages of the various detector types. At this point enough information has been presented to allow the designer to select the detector that is most appropriate for the measurement being made.

Previous generations of spectrum analyzers have a "quasi-auto" selection mechanism. Examples of quasi-auto behavior include changing to "sample" detector upon enabling the noise marker function, or when turning on trace averaging, then returning to the original detector type upon leaving noise marker or averaging. Many modern analyzers allow automatic or manual selection of detectors.

**Summary**

The right detector type allows accurate noise measurements, CW measurements, adjacent-channel power measurements, as well as others. In addition, detector types allow unification of FFT and swept analysis techniques.

**References.**


**About the author**

Joe Gorin is a master engineer at Agilent Technologies. He joined Hewlett-Packard Company, which spun off Agilent, immediately upon graduating from MIT with SBEE and SMEE degrees in 1974. Most of the years since have been spent concentrating on the development of new spectrum analyzers. He can be reached at joe_gorin@agilent.com.