When and How to Apply FFT-Based Spectrum Analyzers

by Mike Beane, Contributing Editor

Spectrum analyzers are designed in two hardware configurations, so dissimilar that it is difficult to recognize them as performing the same function. Depending upon the application, each configuration has its place in the engineer’s arsenal of test tools.

A classic spectrum analyzer is a narrowband radio receiver tuned rapidly over a band of frequencies. The output signal of the receiver is plotted or graphed as the vertical component against the frequency as the horizontal component. This plot usually is done in real time on an oscilloscope screen. This classical approach is still used for frequencies above 200 MHz.

Vast improvements in receiver stabilization and the application of automated controls have resulted in spectrum analyzers that can be used with far less training, setup, and measurement know-how than those available a couple of decades ago. "The capability of an instrument to calculate and make decisions takes the evaluation of the measured results out of your hands and puts it into the hands of the design engineer," said Tom Rittenhouse, application engineer at IFR Americas, formerly Marconi Instruments. "In the past, all phases of the test were a possible source of error."

Aside from fewer knobs to turn, the capability of producing a hard-copy graphical spectrum output has been the single improvement that has kept the classical spectrum analyzer a highly useful engineering tool.

A more recent spectrum-analyzer design produces the same output with a much different technique. This approach uses a digital data acquisition system to capture or sample the waveform of interest and then performs a digital mathematical operation called a fast Fourier transform (FFT) upon the stored data. The result of this process is a set of numbers which, when graphed, is a magnitude vs frequency plot representing the frequency spectrum of the signal being evaluated.

Sri Welaratna, president and CEO of Data Physics, described the data acquisition/FFT type of spectrum analyzer hardware. "Today, the image of a spectrum analyzer is a computer screen with a graphical user interface and the color signal graphics of infinite flexibility. The measuring instrument itself is a digital signal processing (DSP) board with on-board analog-to-digital converters (ADCs) and digital-to-analog converters (DACs)", he explained.

Both techniques work well within their limitations. The data acquisition/FFT technique is limited in the maximum frequency that it can detect, with the ADC that digitizes the input waveform being the limiting factor.

Currently, these devices have an upper limit of around 400 MHz for their conversion speed. The FFT process only will correctly identify frequency information in a sampled waveform if the sampling process operates at least twice the frequency as the highest frequency of interest.

This limitation is known as the Nyquist criteria.

If a frequency higher than one-half the sampling rate is encountered with this type of system, an effect called aliasing occurs. Aliasing causes the frequencies above the Nyquist limit to be read as the difference between the sampling rate and the input frequencies. Any spectrum obtained under this condition is totally erroneous.

Most spectrum analyzers that use the FFT technique include a low-pass filter that eliminates frequencies above the Nyquist cutoff limit before applying the signal to the DAC. While this makes aliasing unlikely, it gives no indication of any frequency above the low-pass filter cutoff.

There is some good news. The hardware for the FFT/data acquisition type of spectrum analyzer is much less expensive than the classic variety, and the setup and operation are less complicated. There also is no delicate detector diode to be damaged by inadvertent overloading, and instrument stability is inherently better in the FFT/data acquisition configuration.

Another benefit was mentioned by Wes Stamper, technical marketing specialist at IFR Americas. "When using an FFT analysis to evaluate the frequency spectrum, the receiver system is completely locked to a reference. As a result, there is no frequency drift in the system, and the signal being tested will be as accurate as the time base of the system," he said.

Digitizing the input waveform provides two advantages over the classical spectrum analyzer. These advantages are especially important when dealing with sporadic or infrequent signals.

The first benefit is a result of the input section being a data acquisition system. The data-acquisition configuration allows data capture to be triggered on an event such as reception of a trigger pulse.

Also, the spectrum will be a captured waveform of known length. So if a waveform is changing, or of short duration, data capture can be easily limited to the known interval. During that interval, no component will be lost, and unwanted signals will not be included.

By comparison, the classical spectrum analyzer will only be sensitive to one frequency at any given instant and possibly miss data that occurs sporadically. This is not a concern for steady-state signals such as a radio- frequency carrier, but can cause incorrect results when analyzing nonrepeating signals such as acoustical signals from shock stimuli or other pulse-induced waveforms.

The FFT is the digital realization of a method to determine how large each component frequency must be to reproduce a waveform. Another advantage of the FFT was pointed out by Pete Watridge, product manager of the Hewlett-Packard Microwave Instruments Division: "An FFT analyzer determines the phase and magnitude of the frequency spectrum. A typical swept-tuned spectrum analyzer only provides magnitude information."

To use an FFT analyzer effectively, we need to know what conditions must be met to assure that it works properly. This leads to some terms that you might encounter on the spectrum-analyzer controls.

FFT length is the first to consider. This is how many points of data are to be included in the FFT. Strictly speaking, FFT lengths must be exact powers of 2.

If the instrument allows you to choose a number other than an exact power of 2, it is performing a behind-the-scenes calculation to add enough extra points to make a data sample with an exact power-of-2 data points before performing the FFT. Since this could introduce an error and requires additional calculations that increase processing time, it always is best to use an FFT length that is a power of 2.

The FFT length, combined with the sample speed, also determines the resolution of the spectrum. For example, if a signal is sampled at 100 kHz for 1,024 samples, the highest detectable frequency will be 50 kHz, and the smallest difference will be 50 Hz. If the number of samples is doubled to 2,048, the resolution will double to 25 Hz. If we increase the sample rate to 200 kHz while keeping the sample size at 2,048, the highest frequency detectable will be 100 kHz with the resolution reverting to 50 Hz.

As this example illustrates, the uppermost detectable frequency is determined by the sampling speed and the frequency resolution or discrimination by the sample length.

As the sample length increases, so does the computational time required to perform an FFT. Specifically, the mathematical operations increase logarithmically with greater length. If your spectrum-analyzer requirement needs fast, high-resolution, high-frequency performance, look for specifications that include higher processing speeds. Better yet, use DSP chips that are hardwired and optimized to perform only this operation at very high speeds.

Spectral Leakage

Windowing is another option when using an FFT. In this operation, the input data set is multiplied by a set of numbers that diminishes the data at both ends of the input data set.

Windowing is an attempt to minimize an effect called spectral leakage. Spectral leakage is a byproduct of one of the constraints under which the FFT was derived.

The frequencies that an FFT can use to reproduce the input waveform must be an integer multiple of the sampling frequency divided by the record length. If a component frequency does not meet this requirement, the FFT substitutes frequencies that it can use to reconstruct the input frequency.

As the input frequency differs from the allowable component frequency, larger amplitudes of more frequencies are required to reconstruct it. This appears on the output plot as an increasing noise floor or wider frequency peaks. Three methods can reduce this apparent noise caused by spectral leakage.

The first method is the easiest—simply increase the sample rate and size. With more points of input, there are more frequencies closer together for the FFT to use and less spectral leakage.

The second method is to change the sampling frequency slightly to find a frequency that minimizes the variance between the FFT frequencies and the input waveform frequency components. This can be done visually, tuning the frequency for a minimum noise floor or narrowest spectral peaks.

The technique of last resort is windowing. This operation only is useful if you are looking for harmonics and wish to exclude or minimize other signals. Using an FFT window increases processing time and distorts the results.

If your FFT analyzer contains a control to select different windows, "no window" usually is not indicated as an option. Instead, a selection labeled "rectangular window" will be present. A rectangular window is the same as no window.

For best resolution, use the rectangular or no window. For minimum spectral leakage, use a Blackman/Harris window. If a window type other than rectangular is used, center the input waveform in the sample window.

Spectrum Analyzers
New Products

Two-Channel Analyzer Provides Printer and Computer Interface

The SR785 Signal Analyzer offers two independent 32-bit channels of 100-kHz real-time bandwidth with a 90-dB dynamic range in the FFT mode or 145 dB in the swept sine mode. Data may be saved to a built-in 3.5" disk drive or outputted directly to a printer, plotter, or a host computer via GPIB or RS-232 formats. The 8-MB memory is expandable to 32 MB. $10,950. **Stanford Research Systems,** (408) 744-9040.

Analyzer Targets Cable TV Needs

The 2625 Spectrum Analyzer covers frequencies from 150 kHz to 1.05 GHz with a dynamic range of 80 dB. It accepts up to a +20-dBm input signal and has a built-in step attenuator. Scan widths are switch-selectable from 50 kHz/div to 50 MHz/div. A 4-digit LED identifies the tuned center frequency. The unit weighs 13 lb. $2,195. **B+K Precision,** (714) 237-9220.

Field Frequency Analyzer Achieves Minimum Size

The SignalCalc® ACE PCMCIA Data Acquisition Card and Software weigh in at just 2 oz. When installed in a laptop computer, these components constitute a portable signal analyzer and data acquisition system that simplifies field collection, storage, and review of collected vibration data. The Windows-based software includes full FFT capabilities and has optional add-ons for high resolution, throughput-to-disk, replay, and ActiveX connectivity. Call company for price. **Data Physics,** (408) 371-7100.

Signal Analyzer Targets Digital TV Broadcast Market

The HP89441V VSB/QAM Signal Analyzer performs comprehensive testing of the FCC-mandated digital TV transmission format including vector modulation analysis of Quadrature Amplitude Modulation (QAM) and Vestigial Sideband (VSB) formats. It operates over a frequency range from 0 to 2.65 GHz. The full-color screen output includes eye, constellation, and vector formats. An optional second input channel allows simultaneous view of baseband I and Q channels. $58,300. **Hewlett-Packard, Microwave Instruments Division,** (800) 452-4844, ext. 5522.

Portable Spectrum Analyzer Has Microwave Capability

The AN1800 Spectrum Analyzers have a 7-in. color LCD and a built-in frequency counter accurate to 1 Hz. They also offer DSO and FFT functions. The fundamental frequency ranges from 9 kHz to 2.9 GHz with options to 26.5 GHz. The amplitude measurement range is -135 to +30 dBm. Digital filters enable bandwidth resolution selectable from 3 Hz to 30 MHz with ±300 divisions of pre- and post-trigger range. The memory stores up to 99 traces. From $15,695. **IFR Americas, Inc.,** (800) 835-2352.

Spectrum Analyzer Offers Full CDMA Measurements

The FSE Series Spectrum Analyzers feature a 116-dB dynamic measurement range and a 0-dB figure of merit to direct adjacent channel power measurement for W-CDMA applications. The unit has a full-color 9.5" LCD, a printer/plotter output, and disk storage. Specifications include an input frequency range from 20 Hz to 40 GHz, resolution to 1 Hz, and a full span sweep time of 5 ms. From $29,995. **Tektronix,** (888) 835-2001.