Software Finds, Identifies, And Analyzes Signals In Long-Term "Spectral Haystack"

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Uncovering and identifying RF interference in long-term spectrum capture files and how to solve the problem.

In a perfect world, all receivers would use brick-wall filters; amplifiers and mixers would never distort; metal would never rust; command centers would always coordinate their spectrum operations; and the word "jam" would have meaning only at breakfast. Until then there will be interference and the need for a way to find and identify it and take steps to remedy the problem. This is an increasingly difficult task in today's dense signal environment, akin to searching for a needle in a haystack or trying to find one slightly different tree in a rain forest.

X-COM's Spectro-X software is specifically designed for this purpose. It is a tool to search for "signals of interest" within long recordings of spectral emissions over broad swaths of spectrum -- even when the signal capture is hours or days in length. Using its four internal search engines, Spectro-X can find the signal in the spectral haystack; show the user how the signal behaves over time, when it occurred, at what location it was recorded; and perform numerous other useful analyses. Features have recently been added to make the process easier and faster and include new functions that enhance analysis results. Spectro-X is well-suited for applications ranging from signals intelligence to spectrum management and verification testing of radar, EW, ECM, and wireless systems.

The examples used in this article are focused on interference as this is a simple way to show what the software can do. However, it's important to note that this software as well as the cited hardware can be used in applications that have nothing to do with interference, such as evaluating the performance of various types of systems to ensure that they comply with specific standards; long-term monitoring of specific locations for intelligence-gathering purposes; and many more.

Clearing the Spectral Fog

If interfering signals were always strong, appeared all the time, or were otherwise obvious, interference mitigation would be vastly easier. Unfortunately, the offending signal is more often than not either weak, appears at random, similar or even identical to the one it is interfering with, cloaked by stronger signals, or appears infrequently, making long-term signal capture, storage, and analysis essential. Capturing, digitizing, and storing spectrum with high fidelity is performed using hardware dedicated to this purpose.

For example, X-COM's capture and storage recorder, the IQC-2110, records and stores up to 400 hr. of I and Q signals from the output of a signal analyzer using a 16-bit DAC to ensure no degradation in fidelity and has a signal capture bandwidth of up to 110 MHz. The CPG-2110 continuous playback generator converts digital I and Q waveform samples to analog I and Q waveforms and drives a vector signal generator to modulate an RF carrier and recreate an RF spectrum with a bandwidth up to 150 MHz. Finding, identifying, and analyzing the signal or signals of interest is the domain of Spectro-X.

Hardware for capturing this information ranges from spectrum analyzers that have limited bandwidth but output I and Q signals with exceptional fidelity, to X-COM's Wideband Acquisition Record and Playback (WARP) system, which directly captures up to 6 GHz of bandwidth (either DC to 6 GHz or any 6 GHz of bandwidth downconverted from higher frequencies), 400 times that of any other similar system. The latter is a complete hardware and software platform for capturing, digitizing, storing, playing back, and analyzing recordings for periods up to 44 min. (or more) at full bandwidth.

However, comprehensive software that is both easy to use and sophisticated has until now either been written at government agencies or prime defense contractors and is typically slow, difficult to use, proprietary, or all three. This new software suffers from none of these drawbacks and as such represents a significant breakthrough in signal analysis.

The user interface is similar to DVR software that a user commands to play, move forward or backward, pause, fast-forward, and jump to various places in a recording. X-COM's RF Editor software, which is the complement to the analysis functions of Spectro-X, works in a very similar manner to professional video-editing software, allowing a broad range of signal modifications. Any signal or slice of spectrum can be moved anywhere among 10 tracks in the recording, creating a new recording designed to accomplish specific goals.

Looking at the Problem

A Navy destroyer is a classic example of interference taken to its ugly conclusion. It supports dozens of low- and high-power RF and microwave emitters operating in close quarters, making it a fertile breeding ground for interference. As a result, it is essential to understand how these systems interact to reduce their potential for rendering each other useless. Less complex environments can provide equally thorny tasks for interference mitigation as well. For example, even a short-term emissions capture over a 150-MHz bandwidth in an urban environment will produce a data file that when viewed in Spectro-X will reveal thousands of signals. Over the same time period in a bandwidth of DC to 6 GHz the file can contain millions of signals. A narrowband file such as 150 MHz would be of use to someone wishing to view the signal environment near a particular operating frequency, while for spectrum managers or intelligence officers, the full bandwidth of 6 GHz can be extraordinarily useful.

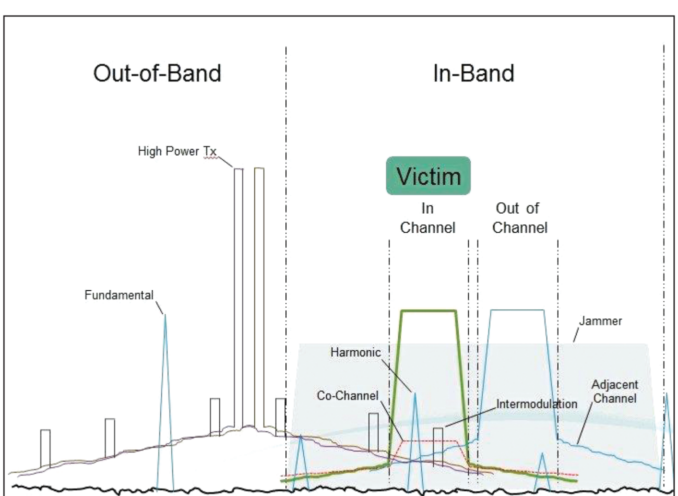

Figure 1 • A "victim" receiver channel along with out-of-band and in-band interference.

The situation is depicted graphically in Figure 1, which shows a "victim" receiver along with out-of-band and in-band interference. Out-of-band interference is an emission, typically spurious or harmonic content from services operating outside the band of interest, that appears in the receiver and if strong enough can desensitize it. Once called "splatter" in the days of analog transmission, it is today referred to as spectral regrowth or intermodulation distortion, both of which are created by nonlinearities in the amplification chain. This is an increasingly common problem in the wireless industry, as more wireless carriers are co-locating on existing base stations to alleviate the headache of deploying new ones and 700 MHz LTE capability is being added to existing UMTS networks.

In-band interference is generated by an emitter operating in the same spectrum occupied by the victim receiver. In a wireless system it can originate from another service or entity that is not entitled to be there, which was the case after portions of the 700-MHz band were auctioned to wireless carriers for high-speed data service. When wireless carriers performed spectrum hunting (and clearing) in all their service areas, they found a variety of these signals – as well as the out-of-band type. The military also suffers from both in-band and out-of-band interference problems throughout the world, sometimes unintentionally but often purposefully, for jamming. As the military uses diverse, non-contiguous portions of the spectrum at various frequencies in different regions of the world, its spectrum managers have the monumental task of keeping military spectrum free of unintentional or intentional emissions.

Dedicated to the Task

A reasonable question is why standard, off-the-shelf test equipment cannot be used "as is" to perform long-duration spectral capture, recording, and playback. The simple answer is that it is not intended for this purpose. Referring to Figure 2, the tan segments to the left of the vertical blue line represent the instrument's processing of signals in real-time. However, once spectrum samples fill the instrument's very limited data buffer, the instrument suffers a form of "blind time" and must first process these

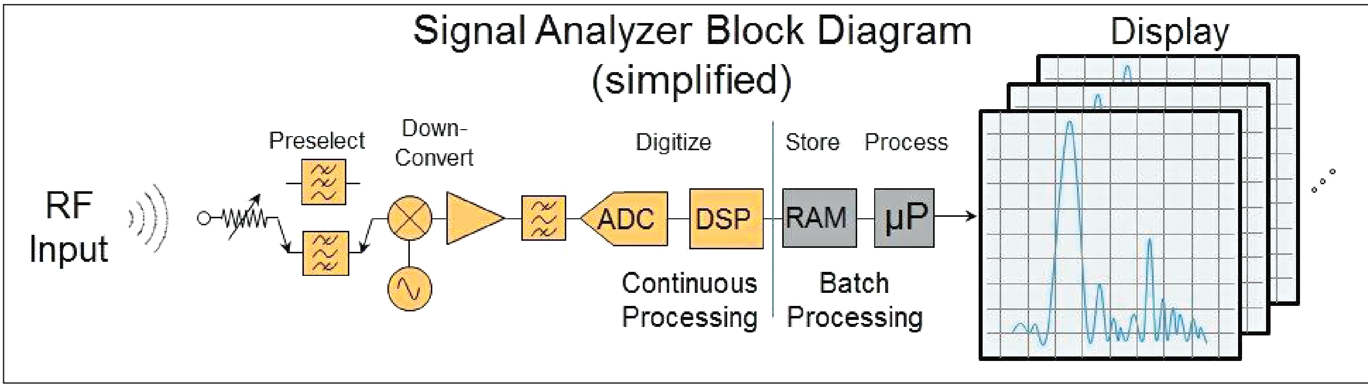

Figure 2 • The limitations of standard test equipment for long-term spectrum analysis.

samples before it can continue sampling. In the interim, information is lost.

In addition, this equipment does not have the ability to store the massive amounts of data captured over even short periods of time. In short, while high-performance vector signal analyzers deliver I and Q outputs with unparalleled fidelity, they are not a complete solution in themselves, and have limitations when applied to long-term signal capture applications. Nevertheless, vector signal analyzers and signal generators are core components of such systems when they are complemented by X-COM's IQC-2110 and CPG-2110.

For example, one approach employs commercial test equipment and is dedicated to long-duration signal captures. The analog signal is tuned, downconverted, digitized, and stored as I and Q baseband samples, with the instrument correcting amplitude and phase distortions in the passband of the IF filter with DSP circuits. The file is marked using IRIG timing and location stamps. Spectro-X is used to deconstruct and analyze the portions of the data file of greatest interest, visualizing it in the time, frequency, and phase domains, and searching the very large data sets for signals of interest. The digital I and Q data can if desired be converted back to analog form via the CPG-2110 and sent to an IQ modulator in a vector signal generator for upconversion to the spectral region of interest.

Looking at this scenario from a test equipment perspective, Figure 3 shows a vector signal analyzer that acts as the front-end downconverter and digitizer and streams I and Q samples to an X-COM Model IQC-2110 for formatting. It is then sent for storage in an X-COM RAID 5 data pack consisting of disk drives with up to 12 Tbytes of capacity. At this point it can be accessed by Spectro-X. Popular instruments from Agilent Technologies, Rohde & Schwarz, and Tektronix are plug-compatible with the IQC-2110 and the CPG-2110 (which in the figure outputs analog IQ signals to an analog signal generator for output at the original or other frequencies).

Application Examples

The best way to visualize the capabilities of the software is through example. Figure 4 shows a continuous 600-s (10-min.) capture from a vector signal analyzer that functions as the receiver front end and downconverter for the X-COM Model IQC-2110, and accompanying data packs. Spectro-X allows visual inspection of the entire capture file and, using a single overview window, shows three areas of potential interest that warrant further investigation. This overview presentation is developed very quickly

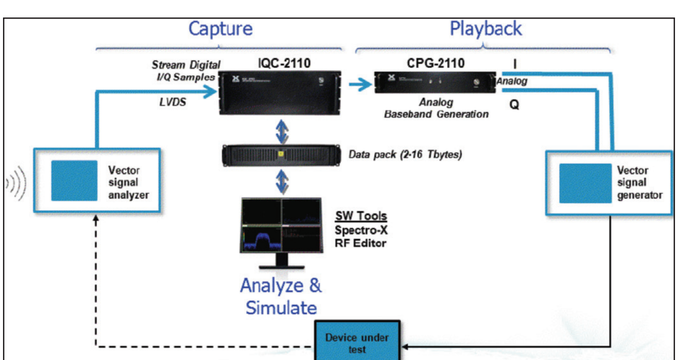

Figure 3 • An approach using standard test equipment for signal capture through playback.

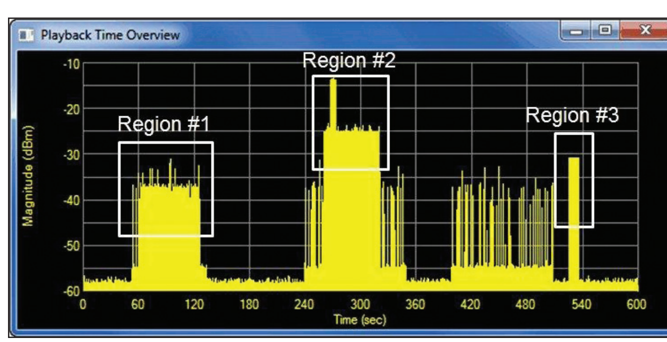

Figure 4 • A 10-min. capture using a vector signal analyzer and the X-COM Model IQC-2110 spectrum recording system.

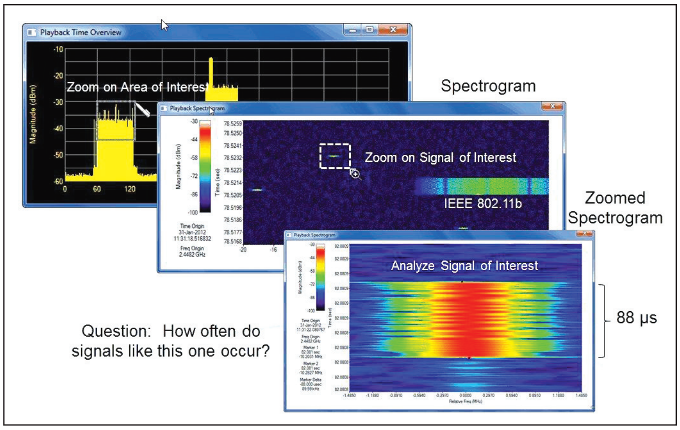

Figure 5 • Zooming-in on a spectral region of interest.

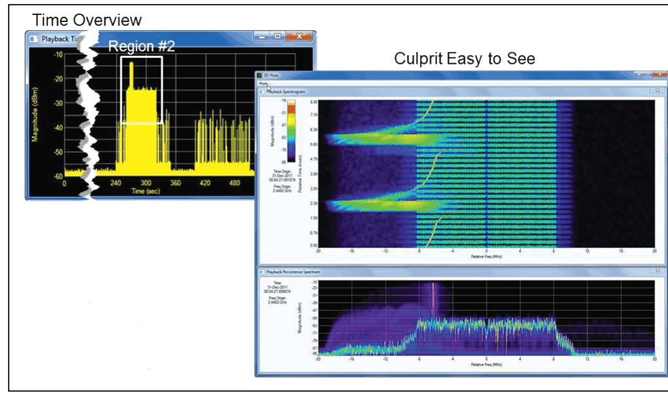

Figure 6 • Spectro-X finds all occurrences of the IEEE 802.11g signal that match an ideal reference at or higher than a user-selectable correlation level.

so that the operator can concentrate on determining the portions of the file that can be ignored and others that should not be.

To examine the details of signals in Region 1, the pen tool in Spectro-X is used to draw a box around a section of the file that contains the time range of interest (Figure 5, top left). If the short burst in the spectrogram appears to be the signal of interest, the user highlights it and zooms-in (in both time and frequency) around the emitter. Closer inspection reveals that the signal s on-time is about 88 µs, so the next step is to determine how often a signal of this duration occurs.

The carrier search function within the software allows all emitters that have a power level above a specific threshold to be found and the results parsed based on a number of parameters including frequency range, bandwidth, start time, signal duration, and peak power. For purposes of this explanation, the results will be pruned based on a criterion of being less than 80 µs and no more than 90 µs in duration, which captures all frequency-hopping emitters. The time and frequency parameters for each result can be displayed to identify the hop pattern of this frequency-agile emitter over time. Comparing this fingerprint to known hopping patterns reveals a match with the Bluetooth standard. Note that the file contains information showing that the hopping carriers started at 60.9 s into the file or at 11:31 am on January 31, 2012.

In Region 2, which includes IEEE 802.11b and IEEE 802.11g signals, the errant emitter is very near the beginning of the start time. The spectrum displays at the right in Figure 6 show an emitter that bursts-on and then moves through some of the IEEE 802.11g carrier. To determine how much impact the signal has on the victim receiver, Spectro-X finds all occurrences of the IEEE 802.11g signal that match an ideal reference waveform at a confidence level of 40% or higher within the time range of interest. In this case, there are more than 92,000 instances of signals that appear to be IEEE 802.11g, as shown by their associated high correlation value, but around 267.72 s into the recording the correlations severely degrade (Figure 7), which just so happens to be when the interferer starts to enter the picture.

In this case, an unintentional interferer is originating at an Internet café, specifically the magnetron in a microwave oven that moves through the IEEE 802.11g signal every time someone heats up a cup of coffee. (We point this out as we made the determination ourselves after capturing the signals from within our building). Each of the cor-

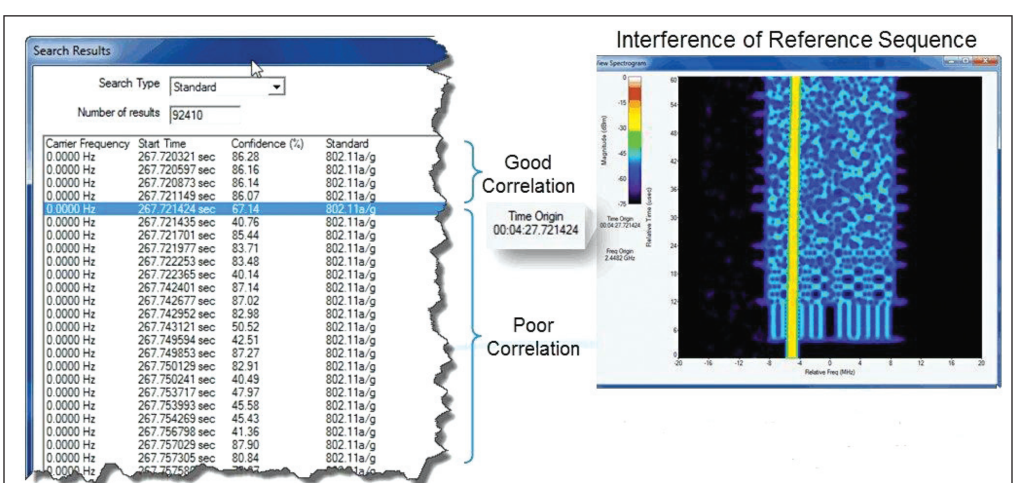

Figure 7 • Signal occurrences below a specific confidence level help identify the interferer.

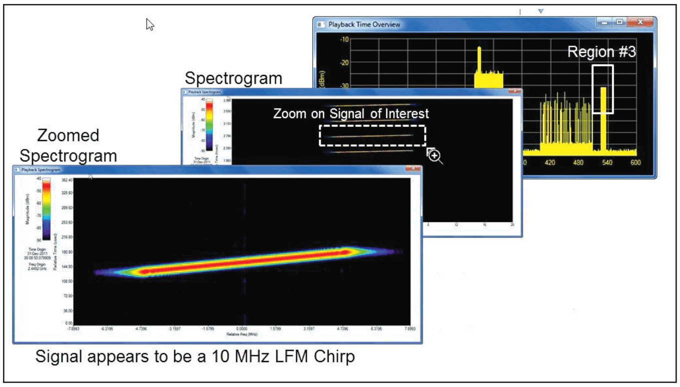

Figure 8 • Region 3 reveals multiple LFM chirps when the pen tool is used to select a region for playback and the zoom box magnifies it to display a single pulse.

relation results shows the spectrogram of the signal and where the interferer was when poor correlation began. Armed with this information, the I and Q data can be exported into vector signal analyzer software, demodulated, and the severity of the interference quantified.

Region 3 contains LFM radar chirps revealed when the pen tool is used to highlight the region for playback (Figure 8). The middle display shows the LFM bursts. Zooming in further shows the details of a single pulse, but the question is whether some pulses are different than others and how many times these non-standard pulses occur. The waveform search tool in Spectro-X helps provide the answer by comparing a marker-delimited copy of the zoomed, single pulse with all of the signals in the recorded pulse train. The correlation limit is set to a low value of 20% to see all matches at this level or higher. While a sample from an actual captured file is used in this case it could also be a waveform created in MATLAB or some other simulation tool.

The search (Figure 9) shows that there are more than 20,000 pulses that correlated 99% or higher, after which one pulse correlates at about 21% -- the "needle" in the haystack of similar but not identical needles. This is a 10 µs-long, non-linear chirp that has both a sinusoidal phase and parabolic frequency. Having found it, the pulse can be analyzed using vector signal analysis software.

Fighting Back

It isn't always possible to completely eliminate interference so a compromise must be reached to determine just how much interference the user's system can tolerate. Having analyzed the recorded interference, the resulting file segment can be used to determine what this value might be. Anyone familiar with audio or video editing software will recognize the intentional similarity between it and RF Editor. The software's user interface allows users to drag and drop snippets of recorded data onto any of 10 tracks. Recordings can be replayed at their time, span, and frequencies, or delayed, filtered, and shifted in frequency. Once all waveform segments are in place, a new composite waveform can be built for replay by Spectro-X or a vector signal generator.

To build a simulated waveform, this example uses a recording of an IEEE 802.11g signal when no interference was present. The interfering signal (in this case the microwave oven's wandering magnetron) is overlaid by dragging a recording of this waveform onto

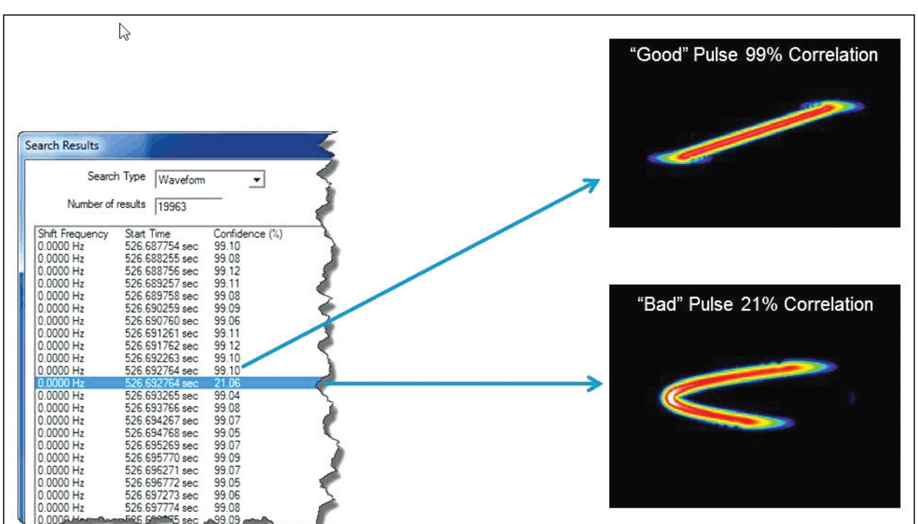

Figure 9 • The point at which good correlation plummets pinpoints a signal variant.

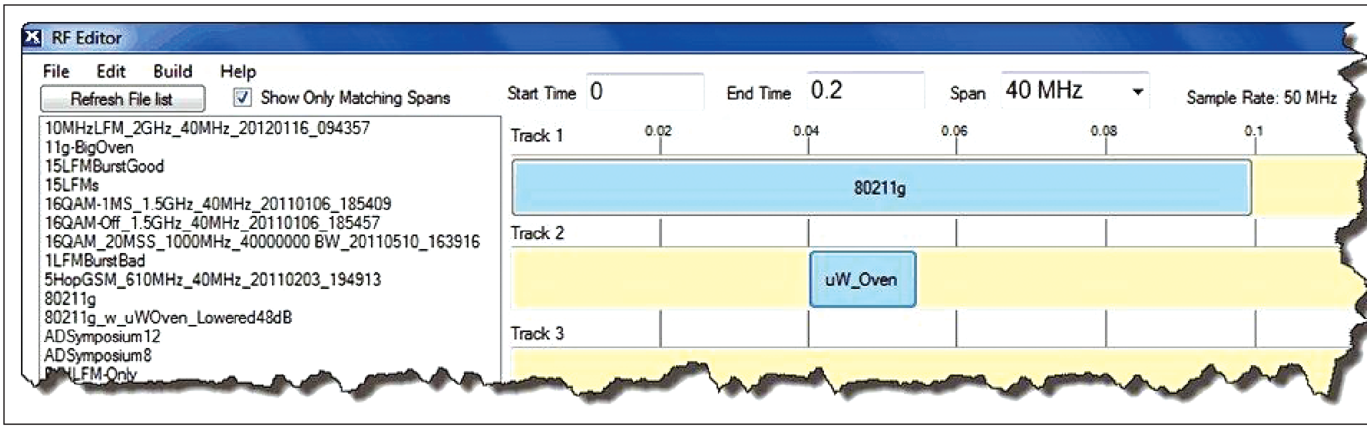

Figure 10 • RF Editor allows the manipulation of any waveform in the frequency domain and lets the user uniquely combine waveforms in time.

track 2 (Figure 10). Its amplitude is attenuated so its peak power is 3 dB below that of the peak power of the IEEE 802.11g signal, which is the level of shielding effectiveness around the oven that would have to be created. When the newly-created spectrum is exported to vector signal analysis software and the 802.11g signal is demodulated, it is apparent that EVM is still degraded, as the interferer sweeps through the various subcarriers. However, its worse-case peak levels are now at acceptable levels. Taking this one step further, by transferring the I and Q files to the data pack, a CPG-2110 can drive a vector signal generator that upconverts the waveform to the desired carrier and ultimately into the receiver under test.

Summary

Identifying signals of interest within a very long spectral recording is increasingly helpful in both commercial and defense applications. The importance of Spectro-X in military applications is perhaps most obvious, as threats are proliferating and adversaries are finding new ways to subvert military communication, EW, and radar signals. As a result, a fast, accurate way to find, identify, and mitigate these threats is more important than ever. However, the software is equally suited for evaluating commercial radar and wireless systems (and others) to determine how they perform when subjected to actual signal conditions and for verifying their performance over time. For spectrum managers, the ability to monitor activity within broad swaths of spectrum to find new interferers can be exceptionally useful as well. These requirements will undoubtedly significantly increase in the future.

About the Author:

Ray Swanson is a product planner at X-COM Systems. He has more than 35 years of experience in satellite network systems engineering, voice-enabled mobile information management systems, and the development of advanced electronic flight information systems for light sport and experimental aircraft.