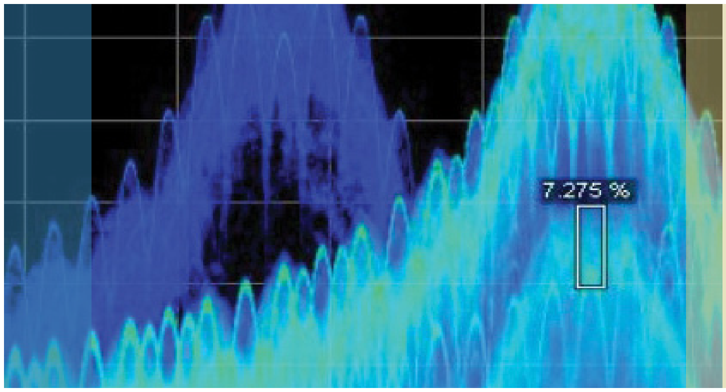

Tektronix and X-COM Systems Platform Provide Unique Capabilities for RF Signal Capture and Analysis

Application Note

Spectrum monitoring, radar and wireless system testing, signals intelligence (SIGINT), electronic intelligence (ELINT), communications intelligence (COMINT), and electronic warfare (EW), all routinely perform or can benefit from the ability to capture signal activity “off-the-air” continuously over long periods, digitize and store it, and play it back. High-performance spectrum and signal analyzers are excellent tools for capturing signal information over short periods, digitizing it with high fidelity, and storing it. However, when long-term signal capture is required, spectrum analyzers can be employed as the “front end” of a system that can store continuous signal-capture data for hours or days. The spectrum analyzer contributes even more when it provides image-free signal capture, can trigger on and mark many types of events even when obscured by stronger signals, and can identify signals in complex electromagnetic environments.

This application note describes such a system comprised of either a Tektronix RSA5000B or RSA6000B real-time spectrum analyzer and the X-COM Systems IQC5000A RF record, storage, and playback system. It also illustrates the benefits of the Tektronix AWG70000 Series arbitrary waveform generator when used to play back the signals in analog form, generally after being processed by software such as X-COM’s Spectro-X and RF Editor and Tektronix SignalVu-PC and RFXpress.

Figure 1. A frequency spectrum chart shows the dense packing of RF and microwave allocations.

The Challenge

Regardless of the application, the process of finding signals in dense electromagnetic environments is difficult and getting more so thanks to the proliferation of services, especially below 6 GHz. One look at a frequency spectrum allocation chart tells the story (Figure 1). The most appealing frequencies, those between about 150 MHz and 3 GHz are already full to capacity, so wireless carriers are resorting to extraordinary means.

For example, to find the spectrum necessary to achieve the blistering data rates required of LTE-Advanced, they are cobbling together the required 100 MHz of bandwidth from different sectors of their allocated spectrum. In this environment, finding a signal originating from someone whose goal is to avoid detection is exceptionally difficult, especially if it is weaker than other signals at the same frequency.

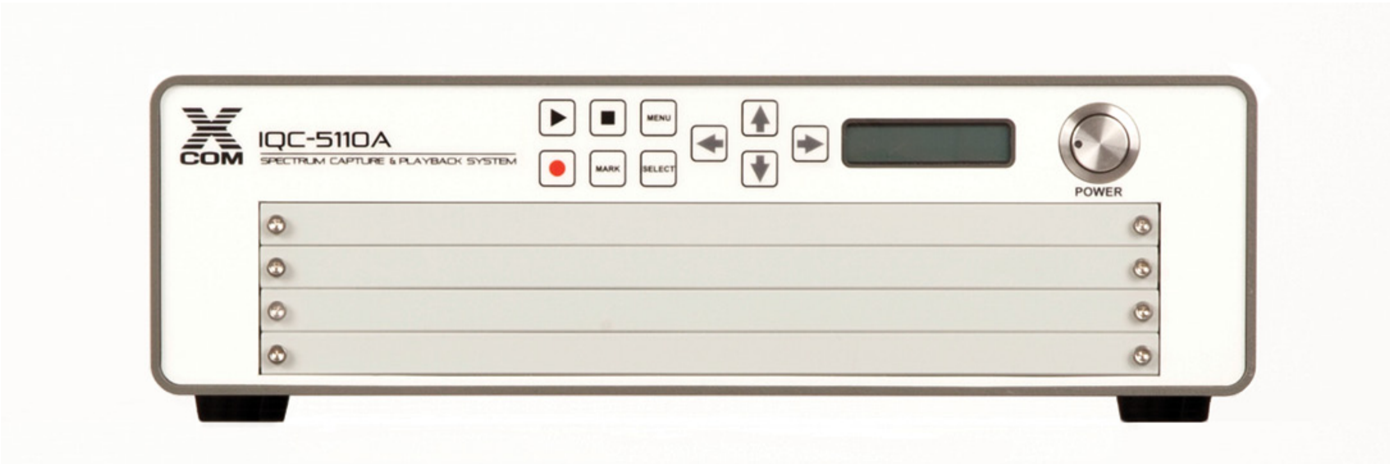

Figure 2. X-COM's IQC5000A RF capture, record, and playback system.

Consequently, finding and identifying the signals requires a combination of an extremely sensitive receiver, error-free signal capture, and the ability to maintain the original fidelity of the captured signal. It also requires software that is capable of finding a signal in a signal capture file that could be hours or days long, removing it from its spectral environment and "zooming-in" on it to determine what it is. Beyond this, analysis, characterization, and file manipulation software can operate on the signal capture files to create entirely new, highly modified files that can be used for a variety of purposes.

As stated earlier, real-time spectrum analyzers such as the RSA5000B and RSA6000B employ are designed to analyze signals captured over short periods of only a few seconds or minutes, and thus have minimal internal storage capability. The IQC5000A (Figure 2) significantly expands this storage capacity while maintaining the fidelity of the input signal delivered as digital I&Q samples from the RSA5000B or RSA6000B. The IQC5000A can continuously record and store data over periods ranging from 300 min. at the RSA5000B's maximum bandwidth of 165 MHz to greater than 80 hr. with a 10 MHz bandwidth. The instrument measures only 12 x 3.5 x 10.5 in., weighs less than 10 lb. and has up to 2 Tybtes of internal storage and 16 Tbytes of external storage. It also operates from 120/240 VAC or a 12-VDC source such as a vehicle battery, which makes it well suited for use in the field.

With two independent channels, the IQC5000A can for example, make time-synchronized recordings at a set of frequencies at a first location, and then from a different location to understand how signal characteristics change as the transmitter moves through the environment. The signal-capture files can be analyzed later using the software tools described in this paper.

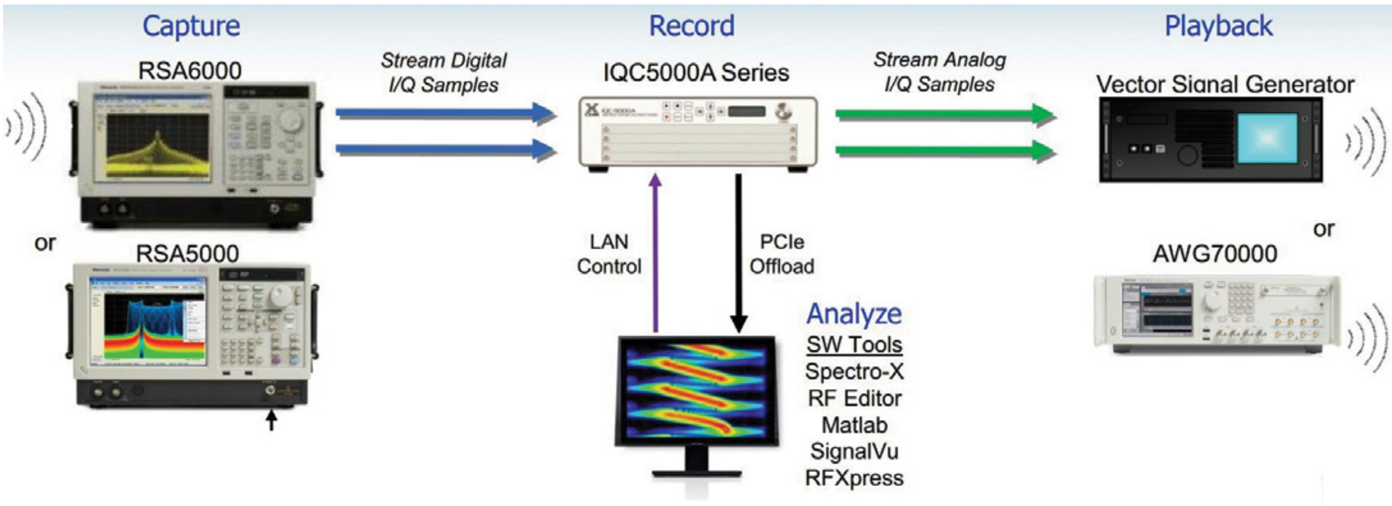

Figure 3. A typical system employing Tektronix spectrum analyzers, the X-COM IQC5000A, signal analysis, characterization, and editing software, and the Tektronix AWG70000 arbitrary waveform generator.

System Description

A system employing the RSA5000B or RSA6000B and IQC5000A is shown in Figure 3. The spectrum analyzer at left forms the receive front end, preselector, and downconverter that presents a digital 16-b I&Q sample stream to the IQC5000A at up to 800 Mb/s. The data stream is stored by the IQC5000A either internally or externally depending on the length of the signal capture. For playback, the IQC5000A converts the I&Q samples to analog form and then streams them to an external source for re-modulation and retransmission.

The source can be either a vector signal generator or the Tektronix AWG70000 Series arbitrary waveform generator that has an output frequency range up to 18 GHz. Higher frequencies can be accommodated with an upconverter. The IQC5000A is operated by control software on a desktop or laptop computer, remotely via Ethernet, or from any computer with an Internet connection.

Unique Benefits of the RSA5000B and RSA6000B

These two instruments may not be the only high-performance spectrum analyzers, but they have capabilities found on no other similar instrument that make them uniquely qualified for the applications to which the IQC5000A is best suited.

Real-Time Processing

The RSA5000B and RSA6000B are real-time spectrum analyzers that by definition perform their processing functions speeds fast enough to keep pace with changes in the input signal. The advantages of a real-time spectral analyzer are best described by how it differs from other analyzer architectures, such as swept-tuned spectrum analyzers and vector signal analyzers.

The architecture of a swept-tuned analyzer makes it best for visualizing stable, unchanging input signals. While it can achieve very high dynamic range, it can only calculate the amplitude data for one frequency point at a time. If a signal changes, which invariably occurs with pulsed radar waveforms and higher-order modulation schemes, it is likely that the instrument will not be able to “see” them. Vector signal analyzers are well suited for analyzing digitally-modulated waveforms that require vector measurements including magnitude and phase information but are less useful when operating on other waveforms.

A real-time spectrum analyzer circumvents the problems associated with transient and dynamic RF signals as it uses very-high-speed digital signal processing performed before it is stored in memory rather than after acquisition. Real-time processing makes it possible to reveal events invisible to other architectures, trigger on them, and store them in memory. Once stored, the data can be analyzed either internally or externally.

Preselection: There’s a Difference

Spectrum analyzers use the venerable superheterodyne architecture that has been a staple of receiver design since Edwin Armstrong invented it in 1918. One of the disadvantages of superheterodyne receivers is that in the process of harmonic mixing, multiple “spectral windows” appear, and the signals present in these windows convert in the spectrum analyzer into the span of interest and may also distort the desired input signal. It also allows numerous spurious signals to appear on the display, which makes it difficult or impossible to identify the desired signal from the rest. Obviously, in the applications described in this discussion, this is highly undesirable.

To solve this problem, a spectrum analyzer uses a tunable preselector filter whose purpose is to remove unwanted mixer images and responses to LO harmonics, effectively “closing” all of the spectral windows except for the desired one

For operation at microwave frequencies, the preselector filter in traditional spectrum analyzers is based on YIG technology, in which the YIG spheres create the filter passband resonances needed to remove unwanted images and responses from the spectrum analyzer’s signal path. Well-designed YIG preselectors can be extremely effective, are comparatively simple and inexpensive to implement, and provide a high level of out-of-band signal rejection. Unfortunately, they are also inherently narrowband, making YIG-based systems incapable of measuring signals whose bandwidths are greater than about 40 MHz.

To circumvent the issue of capturing signals greater than 40 MHz of bandwidth, the approach used by typical spectrum analyzers is to bypass the YIG preselector. When this is done, signals on the other side of the first LO can appear in the IF and thus be display, making it difficult or even impossible to differentiate a real signal from one generated by the instrument. To visualize this problem, consider a system without preselection that is viewing a signal at 12 GHz, which means the LO is 2 GHz away at 14 GHz. The first image will appear in the display at its full amplitude and as there is nothing to attenuate the high-side image. No amount of post-processing can remove it.

To avoid the problems of the traditional approach, the RSA5000B and RSA6000B use a switched-filter preselector rather than a YIG-based approach. This allows the instruments to accommodate both narrow and wideband signal bandwidths as well as pulses with fast rise times and spread-spectrum signals that can cover a broad range of frequencies. The use of switched bandpass filters is more difficult to implement as multiple banks of overlapping filters are required that must be well characterized in amplitude and phase over the entire bandwidth of the instrument.

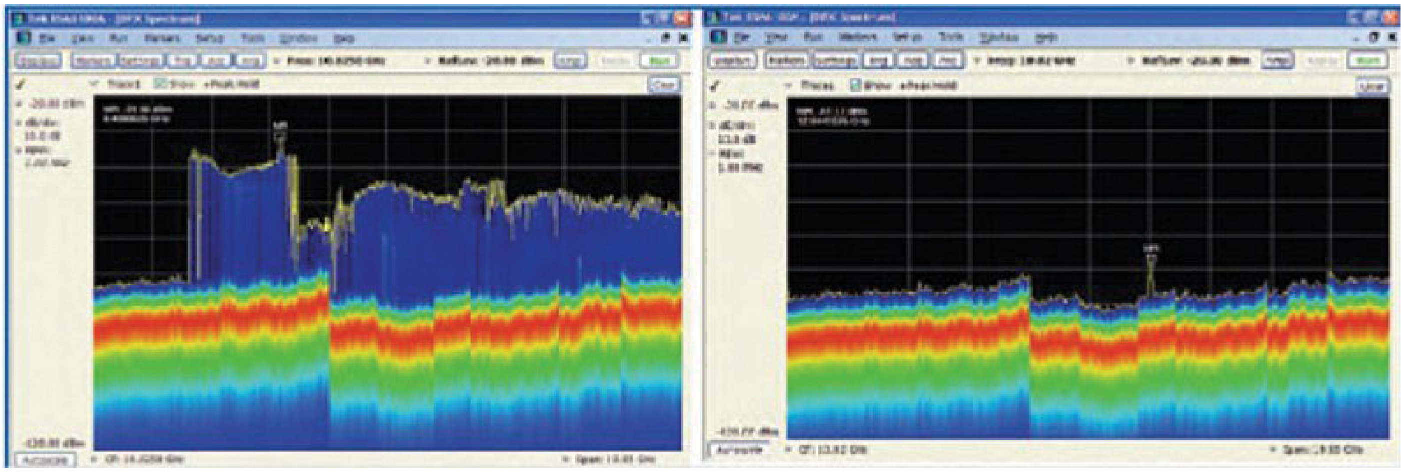

Figure 4. LO leakage from an unpreselected swept spectrum analyzer (left) and the RSA6000B (right) shows an extremely high level of radiation from the former (the upper blue section of the display on left) and virtually none from the RSA6000B.

However, the extra difficulty is well worth the effort, as the analyzer is effectively image-free to the highest frequency in its range, which is not achieved by instruments that do not use this approach. It does introduce some amplitude and phase errors but as they are stable over time and temperature they can be characterized and their effects “de-embedded”, and thus present no problems. In addition, as they are fully corrected, there is no need for the calibration procedures required by their YIG-based counterparts.

Preselection filters also keep internal signals, such as the first LO, from radiating from the RF input connector on the front panel that can produce signals strong enough to be detected by the enemy from quite a distance, making it possible to locate the system. The switched-preselector technology used in Tektronix real-time spectrum analyzers virtually eliminates this problem as the instrument is always preselected as there are no YIG-tuned filters to be bypassed. The effectiveness of this approach when compared to bypassing the preselector is shown in Figure 4.

LO leakage from an unpreselected swept spectrum analyzer (left) is compared to LO leakage from an RSA6000B (right). LO radiation is indicated by the upper blue band. The greatest portion of radiated signals stem from the LO’s fundamental, while the higher-order LO harmonics extend to frequencies beyond 20 GHz. Emissions from the unpreselected analyzer on the left are at such a high level that the instrument would effectively be broadcasting its presence. In contrast, the RSA6000B has almost no LO feedthrough radiation, making it virtually undetectable by scanning receivers.

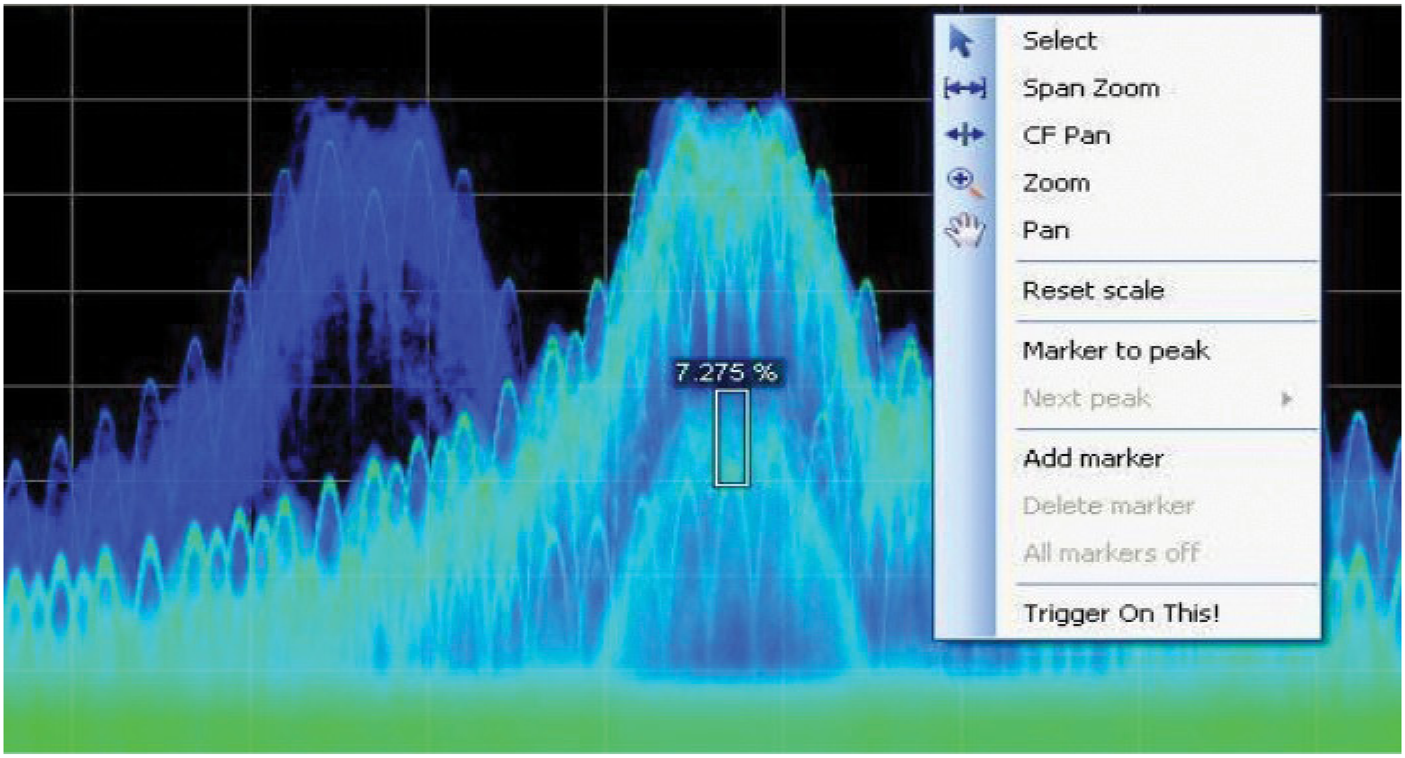

Figure 5. DPX Density Trigger activated by the "Trigger On This" right mouse click allows the RSA to trigger on signals underneath other signals when separated by time and/or distinguished by their density of occurrence.

The Importance of Triggers

When looking for signals of interest, triggers can make the difference between detection and failure as they make it possible to identify specific points in a seamless I&Q capture record, making these points far easier to find, especially when the file contains data recorded over a long period of time. There are a variety of trigger types and many described below are unique to Tektronix real-time spectrum analyzers.

DPX Density Trigger

While other triggering techniques can detect signals that exceed an amplitude threshold, they cannot find a signal at a particular frequency if another signal of higher amplitude is randomly present at the same frequency. Runt triggering addresses some but not all of these signal-under-signal cases but only the Tektronix DPX density trigger can discriminate signals within a specific range of amplitudes and frequencies without the operator having to know any characteristics of the target signal besides where it might show up on the display.

When a target signal appears, the density value increases and as the trigger system monitors the density measurement it activates a trigger whenever the density value exceeds the adjustable density threshold. The threshold need only be set to a level somewhere between the normal density readings and the density caused by the offending signal. The instrument software can also compute the threshold value automatically. If a wideband modulated signal such as a chirp is present and another signal of lesser amplitude is beneath it, both can be seen because the latter signal occupies the frequency all the time and the chirp sweeps through it infrequently.

"Trigger On This" allows the user to point and click to set up the DPX density trigger. For example, with a time-varying signal, right-clicking on a spot within the DPX spectrum display or pressing and holding a finger on the touchscreen for a second produces a menu. Selecting "Trigger On This" lets the trigger automatically adjust the threshold. The display will now only update whenever the automatic threshold is exceeded. The density threshold or the size of the measurement box can be adjusted until the event is acceptably captured. Figure 5 shoes an example of "Trigger On This" in action, successfully triggering on a signal underneath another signal.

Frequency Mask Trigger

Frequency mask triggering, also known as frequency domain triggering, compares the instantaneous spectrum shape on the display to a user-defined mask so that the instrument can trigger on changes in spectrum shape. This ability makes it possible to trigger on weak signals in the presence of stronger ones, which is extremely useful when trying to detect random or intermittent signals in the presence of intermodulation products, transient signals, interference, and suspect emitters. The mask is created by defining a set of frequency points in their amplitudes, point by point either graphically or drawing it on this display with a mouse, or even automatically drawn based on user defined amplitude and frequency offsets from a given spectrum trace. Triggers can be set to occur when a signal outside the mask enters within its bounds or when a signal inside the mask boundary exceeds it.

Time Qualification

Another triggering feature extremely valuable in long-term signal capture is the time qualifier. This allows a trigger event to be qualified as either longer than shorter than a defined time period, or inside or outside a given time window and can be added to whatever type of trigger is selected. A power trigger can be set to enable when a signal exceeds the level of (for example) -30 dBm as well as when it exceeds -30 dBm for less or more than a user-specified time. This ensures that the instrument is triggering on the beginning of an event and not somewhere in the middle.

DPX Mode

DPX technology employed by Tektronix real-time spectrum analyzers was designed to identify and measure transients, continuously observing a wide bandwidth in real time. With the ability to capture events as short as a few microseconds with 100% probability, this capability is invaluable for the applications discussed in this paper. One of the operational modes within DPX is its ability to sequentially step the center frequency, “staring” for a time at each step, which makes it very helpful for finding transient events. This mode is called Swept DPX.

The instrument display shows nearly 400,000 spectrums per second, and a single sweep the instrument captures of events including transient activity over its entire bandwidth. So for example, if a low-duty-cycle 4-GHz-wide radar chirp at 10 GHz is present along with many other signals, each one will be visible on the display at all times within a single sweep. The user need only determine which signal to examine. In many other systems this is impossible even if the instrument is set to sweep very slowly, as only the signals with the greatest amplitude will be shown.

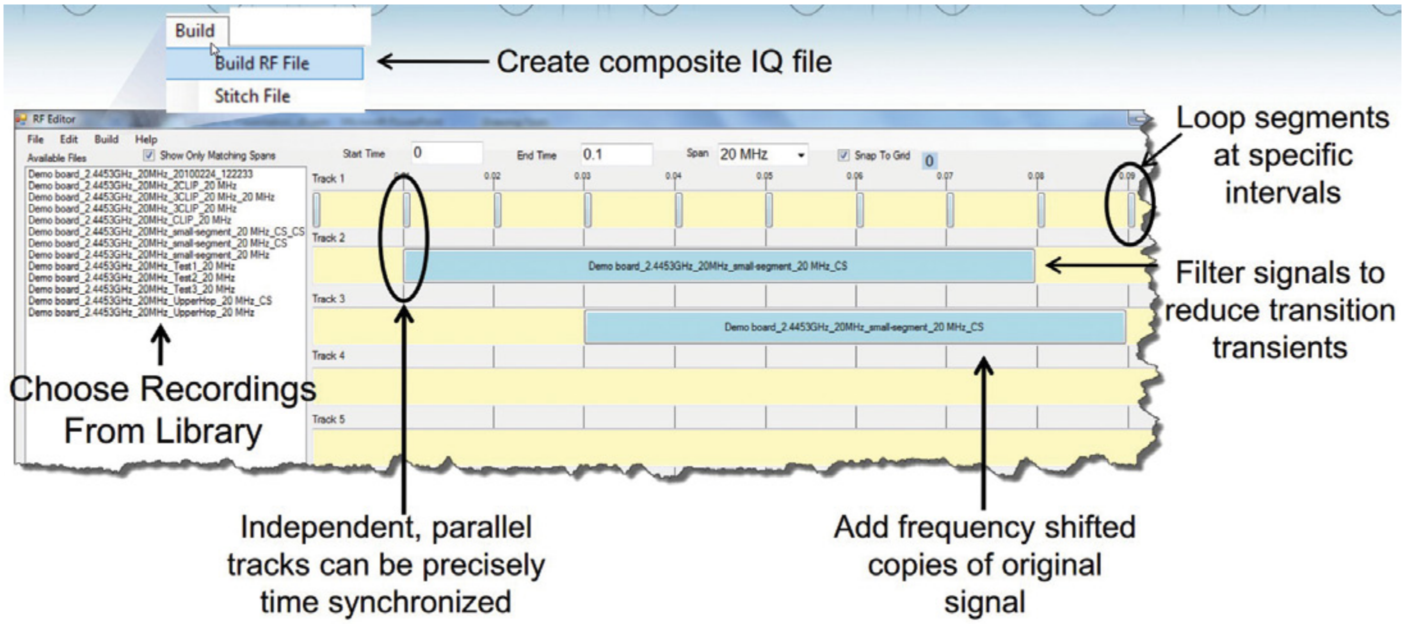

Figure 6. The display from X-COM's RF Editor software shows some of the functions it can perform.

Looking at the Details

Thus far this discussion has focused on capturing, storing, and analyzing signals within the spectrum analyzer. However, in many applications the goal is to perform highly detailed analyses externally from the instrument. Both X-Com and Tektronix provide software tools for this purpose. For example, after capturing the signals with the RSA5000B or RSA6000B and streaming them to the IQC5000A, they can be exported into X-COM's Spectro-X signal analysis software, which provides comprehensive capabilities required to identify a signal or signals of interest within a dense electromagnetic environment using up to four independent search engines.

After signals of interest within the capture file are located and identified within Spectro-X, they can be exported to RFXpress software from Tektronix for re-modulation and re-generation. This software can also create and customize digitally-modulated IQ, IF, and RF waveforms, define baseband I&Q, IF, and RF signals using various modulation schemes, apply impairments such as interference and multipath, and perform many other signal modifications.

The captured I&Q data can also be examined within Tektronix SignalVu-PC vector signal analysis software that allows the signals to be fully characterized to determine their time-variant behavior, modulation quality, etc. These signals or signal segments can then be used to create entirely new signal scenarios using either RFXpress or X-COM's RF editor drag-and-drop RF file editing software.

RF Editor, which complements X-COM's Spectro-X software, allows I&Q signals of any length to be modified and entirely new ones created. It can modify and build signal waveforms in the time and frequency domains, and is well suited for applications such as creating simulated signal threat scenarios and testing of communications, EW, and radar systems using custom stimulus signals. RF Editor can mix, trim, cut, join, repeat, and splice RF files in 10 independent tracks that align to create virtually any type of RF signal with high precision, creating a new recording designed to accomplish specific goals (Figure 6). Snippets of recorded data can be dragged and dropped onto any of the tracks, and can be repeated, lengthened or delayed, filtered, and shifted in frequency before playback.

Whether used alone or together, these comprehensive software tools provide enormous flexibility for locating and identifying signals within long-term signal capture files, analyzing them in extraordinary detail, modifying them, and then creating entirely new files tailored to the specific requirements of the application described in this paper, and many others.

Summary

Spectrum monitoring, radar and wireless system testing, signals intelligence (SIGINT), electronic intelligence (ELINT), communications intelligence (COMINT), and electronic warfare (EW) require the ability to capture, record, and analyze signals over long periods. Their ability to do this depends on the overall quality and capabilities of the equipment employed for the purpose, and the RSA5000B and RSA6000B real-time spectrum analyzers and X-COM's IQC5000A RF capture recorded playback system provide an excellent solution for achieving these goals.

In addition, the unique capabilities of the Tektronix analyzers play significant role in determining the ultimate performance of the system. In particular, their ability to capture signals with high fidelity and stream them to the X-COM equipment along with markers placed in the signal-capture file denoting key events is crucial. Extensive triggering capabilities as well as the ability to virtually eliminate images created in the instrument can be not just helpful but essential in challenging defense applications.

For more information about both the Tektronix RSA5000B and RSA6000B, RFXxpress and SignalVu-PC software as well as X-COM's IQC5000A, Spectro-X and RF Editor software, please contact:

Contact Tektronix:

ASEAN / Australia (65) 6356 3900
Austria* 00800 2255 4835
Balkans, Israel, South Africa and other ISE Countries +41 52 675 3777
Belgium* 00800 2255 4835
Brazil +55 (11) 3759 7627
Canada 1 (800) 833-9200
Central East Europe and the Baltics +41 52 675 3777
Central Europe & Greece +41 52 675 3777
Denmark +45 80 88 1401
Finland +41 52 675 3777
France* 00800 2255 4835
Germany* 00800 2255 4835
Hong Kong 400-820-5835
Ireland* 00800 2255 4835
India +91-80-30792600
Italy* 00800 2255 4835
Japan 0120-441-046
Luxembourg +41 52 675 3777
Macau 400-820-5835
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Singapore +65 6356-3900
South Africa +27 11 206 8360
Spain* 00800 2255 4835
Sweden* 00800 2255 4835
Switzerland* 00800 2255 4835
Taiwan 886-2-2656-6688
United Kingdom* 00800 2255 4835
USA 1 (800) 833-9200

* **If the European phone number above is not accessible, please call +41 52 675 3777**

Contact List Updated June 2013

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