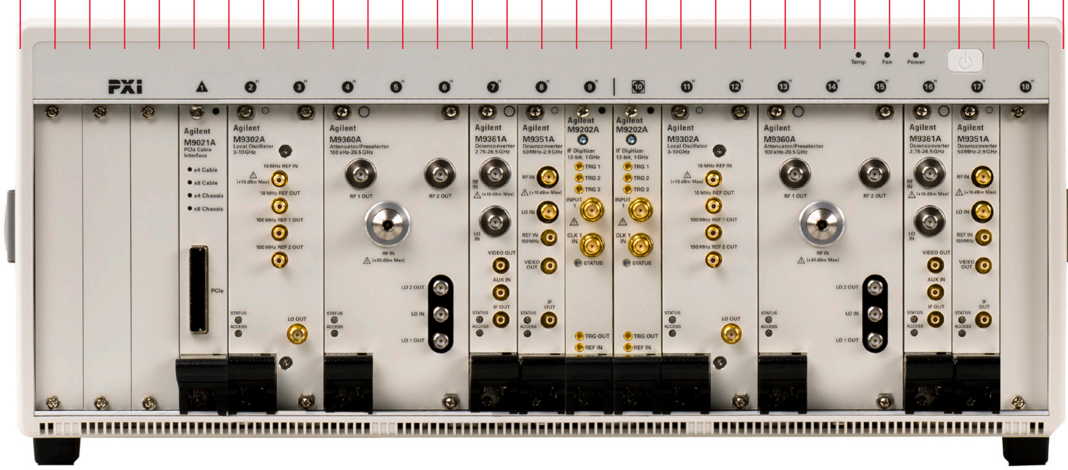
Keysight Technologies
Using RF Recording Techniques to Resolve Interference Problems

Application Note



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Introduction

System engineers characterizing interference in either commercial wireless or Electronic Warfare (EW) applications today face a difficult task. Interference, defined as anything that is not the signal expected, is a highly pervasive problem; one that can be quite difficult to address since its measurement can be unpredictable. Despite the challenge, the task of finding, identifying and analyzing interfering signals, intentional or not, in a crowded spectrum has become increasingly important in a wide array of applications.

This application note introduces a method for using gapless recording to resolve RF interference problems in complex RF environments. The method uses the Keysight Technologies dual-channel M9392A PXI Vector Signal Analyzer with either a regular PC hard disk drive or external mass storage. When recording at wide bandwidths for long durations a RAID storage system is required. Data interface cards and modules are also used, as are Keysight's M9392A with the 89600 Vector Signal Analyzer (VSA) software. With gapless recording, engineers can now measure data continuously over long durations and ensure the capture of all RF events of interest when they occur.

Measurement Challenges

Generally speaking, there are two primary goals of RF interference testing: to ensure interoperability and compatibility. Interoperability testing focuses on design compliance to a published standard, as well as margin testing, which helps engineers understand how well a system meets design criteria in the presence of real-world signal levels and interference. Compatibility testing, on the other hand, focuses on the "unintended interactions" between a system-under-test and other RF systems. It's important for engineers to understand whether radios from different vendors can interoperate with one another, as well as if all the systems in an RF environment can play together nicely. Ascertaining a system's susceptibility to impact from and on other RF assets may also be critical.

Regardless of the RF interference testing in question, a number of critical measurement challenges exist. First and foremost, measuring RF target signals like intentional or unintentional interference in complex RF environments can be unpredictable. Additionally, intermittent failure modes make data capture particularly challenging. Consequently, when the root cause of a problem is not yet known, it can be difficult for engineers to setup a measurement that captures the failure.

How can engineers capture a target RF signal and/or the cause of interference when they don't know what the signal or culprit interferer is, when or where it will occur, or how long it will last? Unfortunately, using a typical signal analyzer performing continuous long-duration recording offers little help.

To better understand why this approach falls short consider the high-level block diagram of a typical signal analyzer shown in Figure 1. The main limitation to long-duration recording is that test equipment typically has limited on-board memory. Signals-of-interest enter the analyzer's RF input and are processed by the subsequent stages, resulting in the displayed waveform shown on the right. Up until the blue vertical line, between the DSP and RAM blocks, all of the signals-of-interest within the instrument's capture bandwidth are processed in real-time, assuming a fixed local oscillator. However, once the samples fill the memory buffer or RAM, the instrument no longer looks at incoming digital samples. Instead, it must process previously recorded samples.

The signal analyzer does not capture any samples while it post-processes the previously captured data, effectively creating a gap in its data acquisition. Consequently, if events occur while the previous event is being processed or if the new event lasts longer than the available memory, it falls into this gap and may be missed. Moreover, the analyzer's trigger setup only captures signals for one set of limited conditions. Once the analyzer fails to capture the event, it is gone forever.

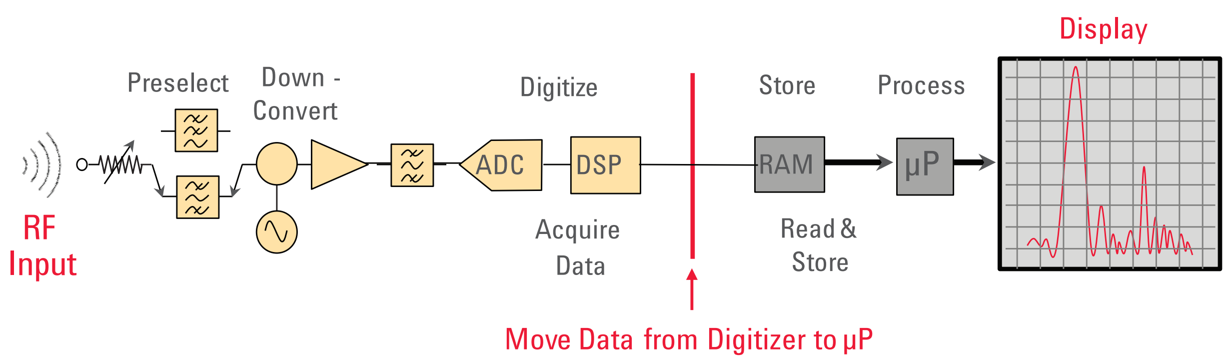

Figure 1. Shown here is a typical signal analyzer block diagram.

Introducing Gapless Recording

While resolving RF interference problems in complex RF environments can be a tricky task, gapless recording offers a viable solution to the measurement challenges presented by the typical signal analyzer. The technique solves the problem of not knowing when or where an interference event will occur, or how long it will last, by enabling continuous acquisition of data over long durations. Because there is no gap in the data recorded, the signal-of-interest, such as an intermittent RF event, is easily captured.

For comparison purposes, consider the data acquisition from a typical signal analyzer with limited on-board memory, as shown in Figure 2. Note the gaps in data that occur once its memory is filled up.

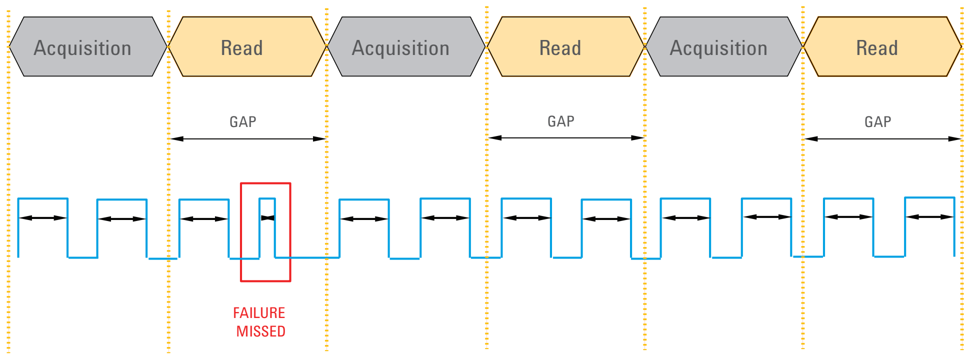

Figure 2. With a typical analyzer, once its memory is filled up, data is "read" from the digitizer to the microprocessor for processing and display. During this "read," any new samples available at the digitizer cannot be processed and are missed, creating a gap in the continuous acquisition of data and resulting in failures being missed.

Now, consider an example of a signal analyzer modified for gapless recording (Figure 3). It is the same signal analyzer shown in Figure 1; however, it now includes a high-speed data link or bus that allows the engineer to move data from memory as it is acquired. By bypassing processing and display updates, and writing the acquired data directly to final storage using a circular RAM buffer, it's possible to create high-bandwidth recordings without gaps in the data. With a circular RAM buffer, the engineer can simultaneously write to and read from it. When recording at wide bandwidths for long durations, a RAID storage system is required.

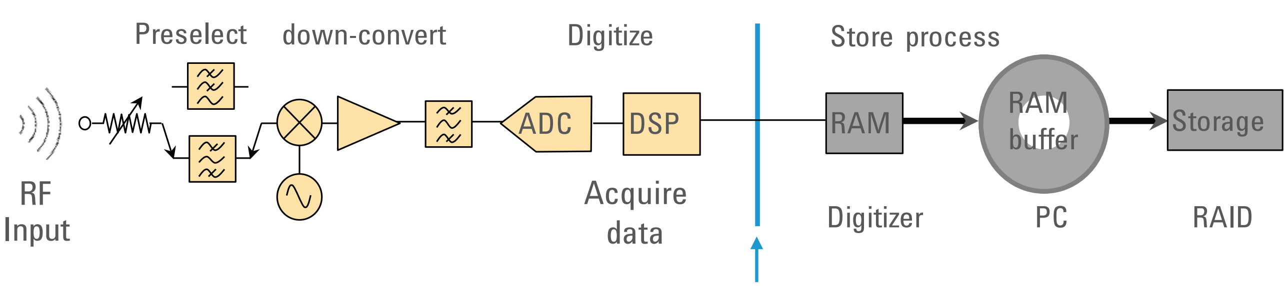

Figure 3. A signal analyzer modified for gapless recording.

Introducing Gapless Recording (continued)

An image of a gapless acquisition taken using the modified analyzer is shown in Figure 4. Note that unlike the gap-filled acquisition in Figure 2, this acquisition is continuous. Recording the acquisition of data does not stop during the "read" because it happens in parallel with the acquisition. Without gaps in the data record, the signal-of-interest—in this case a failure—is easily captured.

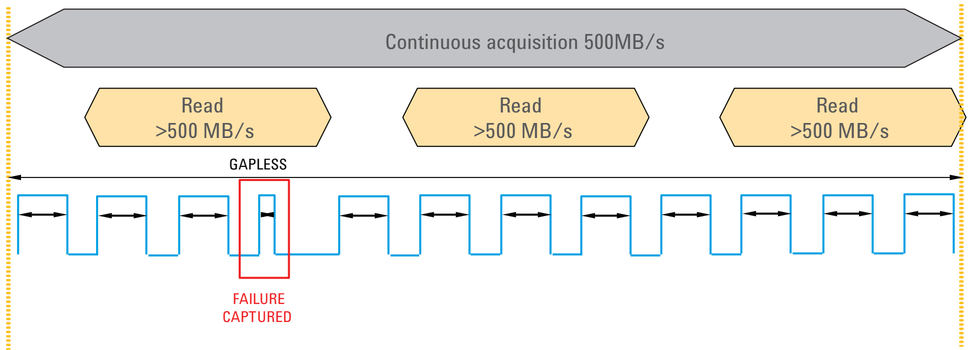

Figure 4. In this gapless acquisition example data is being moved at a sustained rate of 500 MB/s (equivalent to a 100-MHz bandwidth recording).

A Viable Recording Solution (continued)

An example of a gapless recording solution is Keysight's dual-channel M9392A PXI Vector Signal Analyzer, which can provide two independently tunable channels—each capable of recording data at a rate of 100-MHz bandwidth over many hours. The M9392A is a five-module solution. Each module in the system exists as a discrete component in its own right, with its own driver and soft front panel. The overarching control of the five modules is provided by a layer of instrument software called the M9392A.

The M9392A is used with either a regular PC hard disk drive (HDD) or external mass storage. The HDD is used in cases where the required capture duration is only a few tens of seconds. External mass storage can be used with the M9392A for long duration captures requiring more throughput and capacity. When recording at wide bandwidths for long durations, a RAID storage system is required.

Keysight's gapless recording system is available in predefined packages that have been tested to guarantee sustained data rates. The configured systems include data interface cards and modules, and can be used with Keysight's 89600 VSA signal analysis software to speed the process of finding, analyzing and fixing problems.

An example of a configured M9392A recording system with 32 TB of storage is shown in Figure 5. This system can be connected to a PXI chassis or external workstation computer using a very fast PCIe® link. In this case, the JMR RAID system is configured to "look" like an external drive to the PC. To achieve high storage bandwidth, the recorded stream of data is striped (e.g., divided up and written to multiple hard disks in parallel). The striping of data across the disk array is controlled by the RAID host controller on the JMR end of the link.

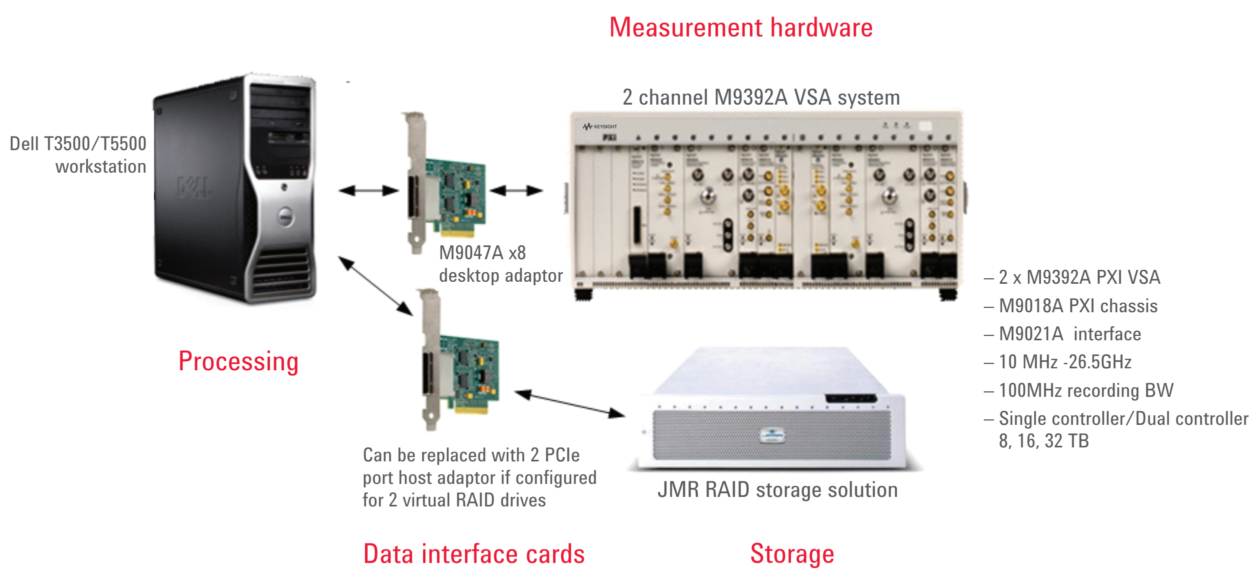

Figure 5. Shown here is Keysight's RF recording hardware configured for 32 TB of storage. The package includes interface cards and modules that rely on the wide bandwidth and fast throughput benefits of PCIe.

A Viable Recording Solution (continued)

Gapless recording data flow

A high-level block diagram implementation of Keysight's wideband recording solution is shown in Figure 6. Note that its' wideband digitizer begins acquisition of data to RAM as soon as it is armed. The M9392A software, running in the PC controller, controls the data acquisition and sets up the circular buffer in recording mode. If the recording mode is configured, the controlling software instantiates a circular buffer in the PC controller RAM. Recording then begins as soon as the trigger is received. For gapless recording, the average streaming data throughput from the digitizer to storage must match the data acquisition bandwidth.

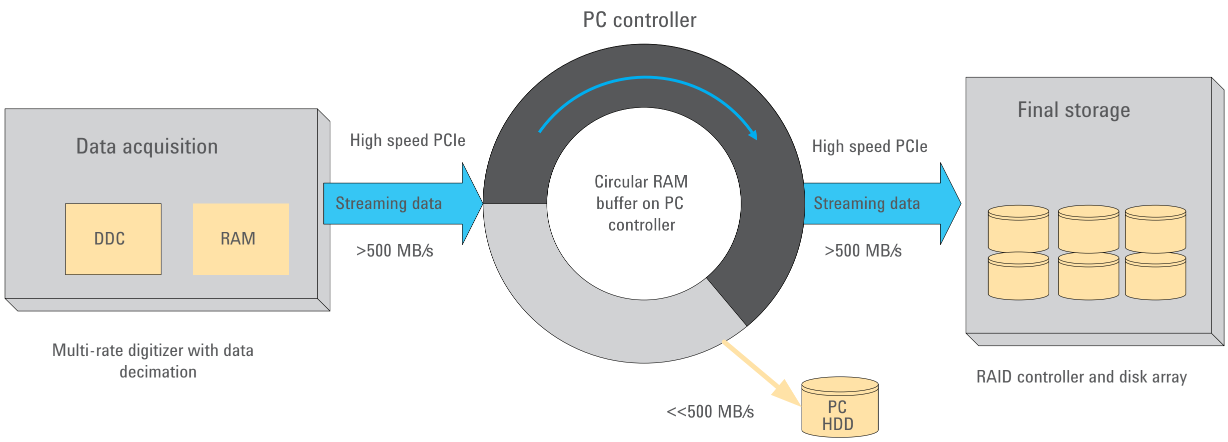

Figure 6. Highlighted here is the gapless recording flow for the M9392A solution. The data in the PC RAM is written out at a very high transfer rate to a RAID array. The RAID is required since a single HDD cannot store data at the necessary sustained rates.

In recording mode, there is a continuous transfer of blocks of data from the digitizer to the PC controller RAM. In a variable-rate system, data decimation saves data bandwidth since only the data needed for the measurement is transferred. This capability is important in scenarios where the digitizer has a very high sample rate or multiple channel support is required. In each case, the RAM in the digitizer and the RAM in the controller would act as buffers between acquisition and final storage when dealing with slight variances in throughput during recording.

A Viable Recording Solution (continued)

Triggering a recording

With the M9392A wideband recording solution, data is block transferred from the digitizer to the controller memory. The actual block size may be quite small. When the digitizer is armed, the controlling software immediately begins the process of copying acquired data to the PC controller RAM. At the same time, the digitizer watches the external trigger input or checks the power on its incoming RF signal using its magnitude trigger. There is both an external trigger and magnitude trigger built into the DDC. Data in the PC RAM is not copied to final storage until the trigger event is detected (Figure 7).

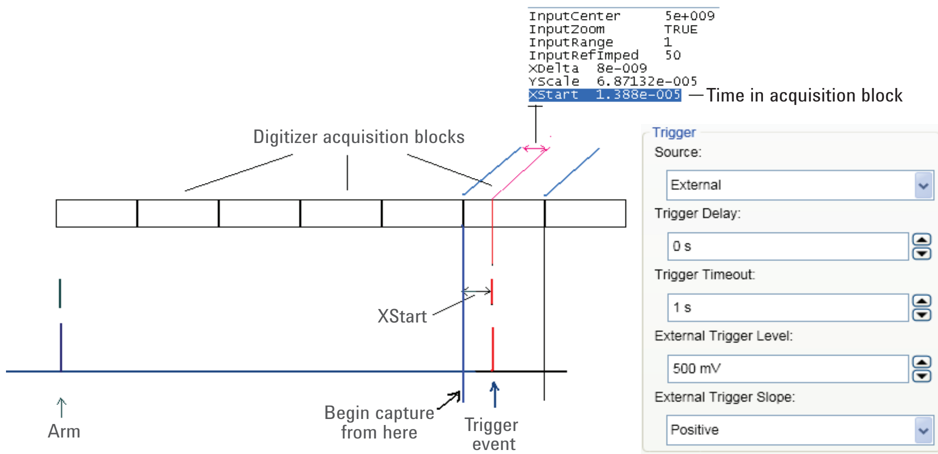

Figure 7. In this implementation, each recording session includes a text header file that instructs any playback system how to process the data. The header file includes RF center frequency, sample period, amplitude scaling factor and trigger event time within the start data block.

A Viable Recording Solution (continued)

Pre-triggering

A key feature of gapless recording is its ability to use large quantities of system RAM for pre-trigger data (Figure 8). Pre-triggered data provides engineers with access to signal data leading up to a specific trigger event.

When pre-triggered data is requested, the size of the pre-trigger allocation is related to the amount of available free RAM. Increasing the PC controller RAM allows for longer pre-triggered acquisitions. The wider the bandwidth captured, the more memory is required for the same acquisition time. As an example, a 125-MSa/s complex sample rate provides a measurement bandwidth of 100 MHz.

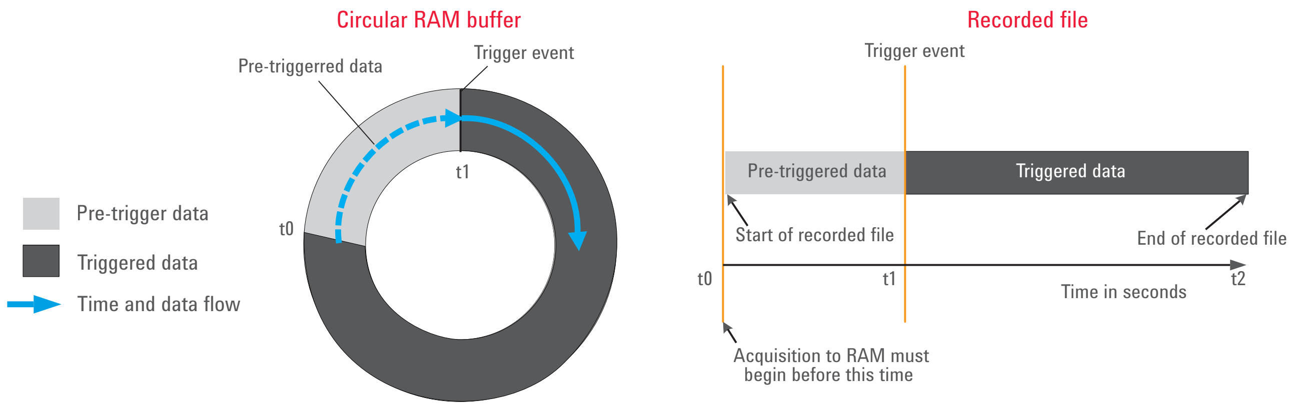

Figure 8. A useful and powerful feature of a recording solution is the ability to use PC controller RAM for acquisition. A 64-bit operating system is required to use more than roughly 4 GB of RAM. In this system, any free memory in the PC controller can be used as a RAM buffer. When using a RAID array, a relatively small buffer is sufficient (e.g., a few hundred MB).

In addition to pre-triggering, another useful feature of the M9392A wideband recording solution is its ability to generate a Windows® time stamp for recorded data so it can be mapped to an absolute time. This allows engineers to associate the time of an interference event with matching physical data, and correlate data from geographically displaced receivers. The M9392A recording solution's trigger simultaneously generates the time stamp and initiates recording.

A Viable Recording Solution (continued)

Dual-channel recording

In a single-channel recording system it can be very difficult to trigger on only the desired signal. As a result, more data is usually recorded than required to ensure the interference event is captured. This additional data takes time and resources to process.

Keysight's two-channel wide bandwidth RF recording system overcomes this limitation with a more discretionary triggering capability (Figure 9). With its independently tunable, dual-channel recording, signals can be acquired and triggered on one channel, while being recorded on the other. The trigger channel can be any frequency and bandwidth. This allows the engineer to trigger off of specific signals and not just any arbitrary signal within the 100-MHz recording bandwidth.

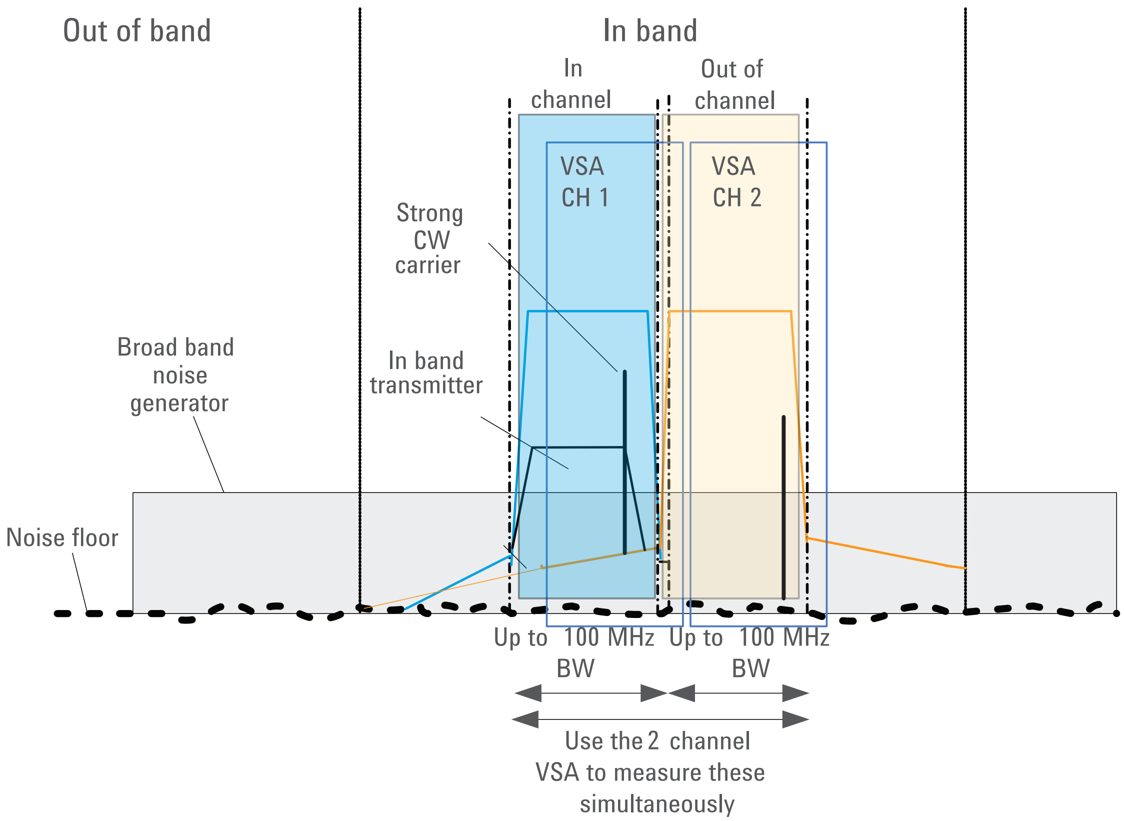

Figure 9. In this example of a two-channel recording, each channel is independently tunable and can acquire different amounts of data at a different frequency or bandwidth. Here, both channels are set to recording mode.

For instance, if a magnitude trigger is set in a full 100-MHz bandwidth, any signal greater than the threshold (even signals we don't want to trigger off) will initiate a recording. In a crowded spectrum, this mechanism leads to false triggering of recordings in a single-channel recording system. Keysight's dual-channel technique, although not perfect, offers a much more robust solution. It reduces the likelihood of false triggering and provides an innate ability to record just the data that's needed. By enabling more efficient discovery of the signals in the RF environment, such discretionary triggering saves a great deal of time and also helps the engineer more effectively solve interference problems.

A Viable Recording Solution (continued)

Signal analysis software

A key benefit of the M9392A is that it creates streaming files directly compatible with the 89600 VSA software (Figure 10). This software provides deep analysis of select interference events or signals discovered during the search for interferers. Combining the M9392A modular hardware with the 89600 VSA simplifies and reduces the time to find target signals-of-interest. It also speeds up the process of analyzing and fixing problems.

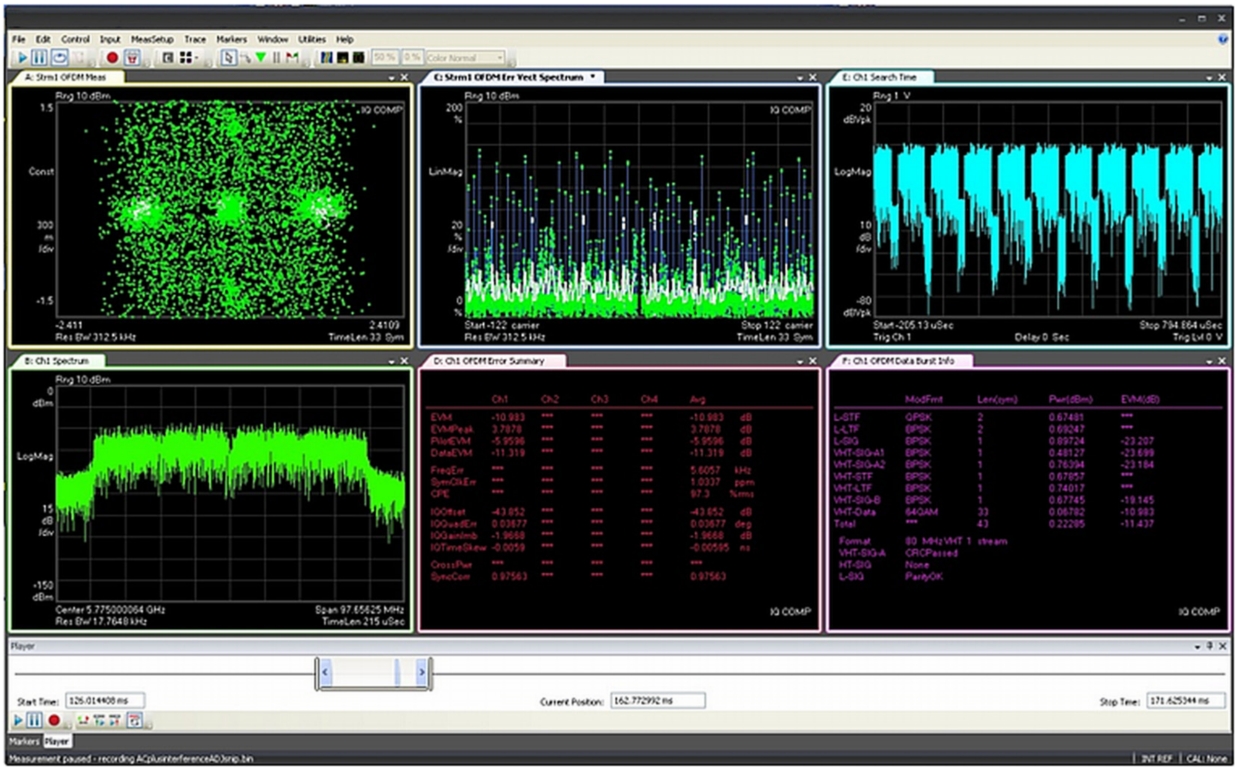

Figure 10. With the 89600 VSA, engineers get a thorough analysis of selected data obtained during the gapless recording process.

Understanding RF Interference

To better understand why RF interference is so complicated and difficult to track down, consider the image in Figure 11, which shows the desired channel where the victim receiver operates. It is assumed that the channel is well designed, possessing both good sensitivity and selectivity.

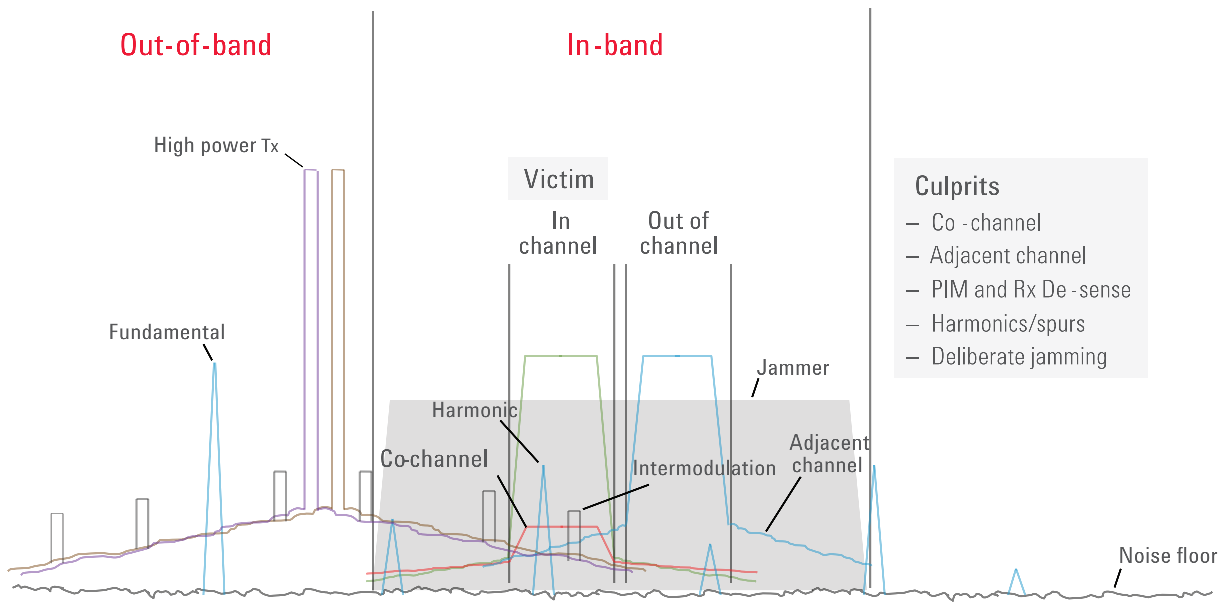

Figure 11. Different forms of interference are shown here, along with how various types of interferers can impact a victim receiver.

As the figure illustrates, interference exists as either in-band or out-of-band. In-band interference, in-channel or out-of-channel, is an undesired transmission from a different communication system or from a radiator that falls inside the operating bandwidth of the victim's system. This type of interference passes through the receiver's channel filter and if the interference amplitude is large relative to the desired signal, the desired signal is corrupted.

Other forms of in-band interference include co-channel interference and adjacent channel interference. Co-channel interference occurs when another radio operates in the same occupied spectrum as the victim. While it is one of the most common culprits in the cellular industry due to frequency reuse plans, military systems can also suffer the same fate.

Adjacent channel interference results when a transmission at the desired frequency channel produces unwanted energy in other channels. A fairly common type of interference, it is primarily created by energy splatter out of the assigned frequency channel and into the surrounding upper and lower channels. This energy splatter is often referred to as intermodulation distortion or spectral re-growth, and is created by the nonlinear effects in the radio transmitter's high-power amplifiers.

One form of interference that is often difficult to troubleshoot is out-of-band transmissions, such as Passive Intermodulation (PIM) distortion or RF overload. PIM is caused by high-power transmitters in the vicinity of the victim receiver. Here, dissimilar metals near large broadcast antennas can act as nonlinear junctions (e.g., diodes) to create intermodulation products that fall in the passband of the victim receiver.

Understanding RF Interference (continued)

RF overload also occurs when operating near high-power radiators. In this case, electromagnetic energy from the radiator couples into the victim's antenna and RF front-end, regardless of frequency, desensitizing the victim's receiver. In areas of high RF congestion, such as shipboard environments, this coupling is often strong enough to physically destroy RF front-end circuitry. Harmonics and spurs from out-of-band transmitters can also be problematic, since they block the victim's ability to receive normal transmissions.

Thus far, the types of interference discussed have all been forms of unintentional jamming of a victim receiver. However, EW operators and engineers must also deal with intentional jamming such as barrage jamming, which transmits a band of energy intended to saturate the victim's RF front-end, degrading its ability to receive intended messages (Figure 11).

In addition to having to consider all the different types of RF interference, a further complication in the process of detecting and testing for RF interference is the temporal nature of the interfering waveforms. While Figure 11 clearly shows these waveforms as steady-state, the time and intensity of each interferer is unpredictable, which makes isolating the interferer a real challenge.

Resolving RF Interference Problems with a Structured Process

Even with gapless capture, the task of resolving RF interference problems is challenging enough that it deserves to be guided by a systematic process. One such process that builds knowledge of the RF environment, while allowing engineers to record information in the frequency band over a long duration is shown in Figure 12. It includes the following steps:

Step 1. Capture

In this step, data is acquired using long-duration recording to ensure the capture of the interferer event. Long duration is required because the signals in the RF environment are often long duration. Also, RF environments change over time and typically have crowded spectrums. Moreover, the increasing bandwidth of modern communication signals means the noise spectrum is wider and interactions are often intermittent, subtle or transient.

Step 2. Search

Once acquired, a recording is played back and analyzed in the lab, as necessary, to extract information about the interferer. Signal search tools, which can perform automatic searches based on many different criteria, are highly recommended for finding interferers in very large records. The search results in a list of signals from the data record that matches the criteria. Once found, these signals can be clipped out and played back using a signal analysis application.

Step 3. Re-Capture Data

Once the engineer has a better understanding of the problem scenario or what the potential interferers are, it may be necessary to capture more specific recordings. In this optional step, the engineer uses that knowledge of the interferer to trigger additional recordings with better signal-to-noise ratio. These recordings can focus on a specific reaction of a victim receiver to a specific interferer. Here, a dual-channel recording system may prove especially useful as it can be configured to use one of its channels to trigger the recording.

Step 4. Analyze

Finally, the engineer can uncover the effect of the interferer using analysis software.

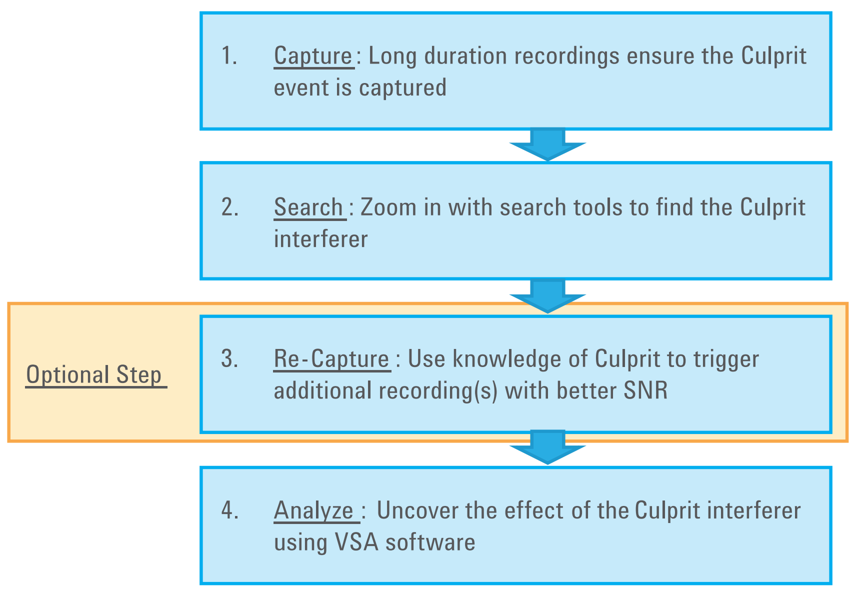

Figure 12. Acquiring knowledge of the RF environment is easy using this structured flowchart.

Utilizing the steps in this process, engineers can efficiently use RF recording to record, search and analyze target signals in complex RF environments.

Resolving RF Interference Problems with a Structured Process (continued)

Application examples

The M9392A wideband multi-channel recording solution allows engineers to run a complete set of scenarios one time and then conveniently analyze them offline. It can be applied to solve a range of issues, including: general wide bandwidth RF recording, simultaneous measurement of RF and IF signal components, recording of frequency hop events in military communications and EW, the response to an EW stimulus or EW scenario recording, and recording of events that are difficult to trigger or can easily be easily false triggered. Some specific application examples are:

Adjacent Channel Interference

In Figure 13, the victim receiver in channel 1 suffers a severe degradation in RF performance when an adjacent channel is transmitting. Spectral leakage is suspected based on signals found in a previous long duration capture. That recording provided a decent picture of the signal that appears to be causing the degradation. Given this information, one channel is assigned to measure the out-of-band signal, configured with a specific frequency, bandwidth and magnitude. This allows the engineer to trigger, with minimal risk of a false trigger, the recording of the victim channel when the interferer interference is present. Since this allows us to make a short, targeted recording it is easy to find, then clip out data and analyze it using the 89600 VSA software. A recording of both channels would provide evidence of the cause and effect and is useful when mitigating steps need to be taken against whoever is transmitting the interfering signal.

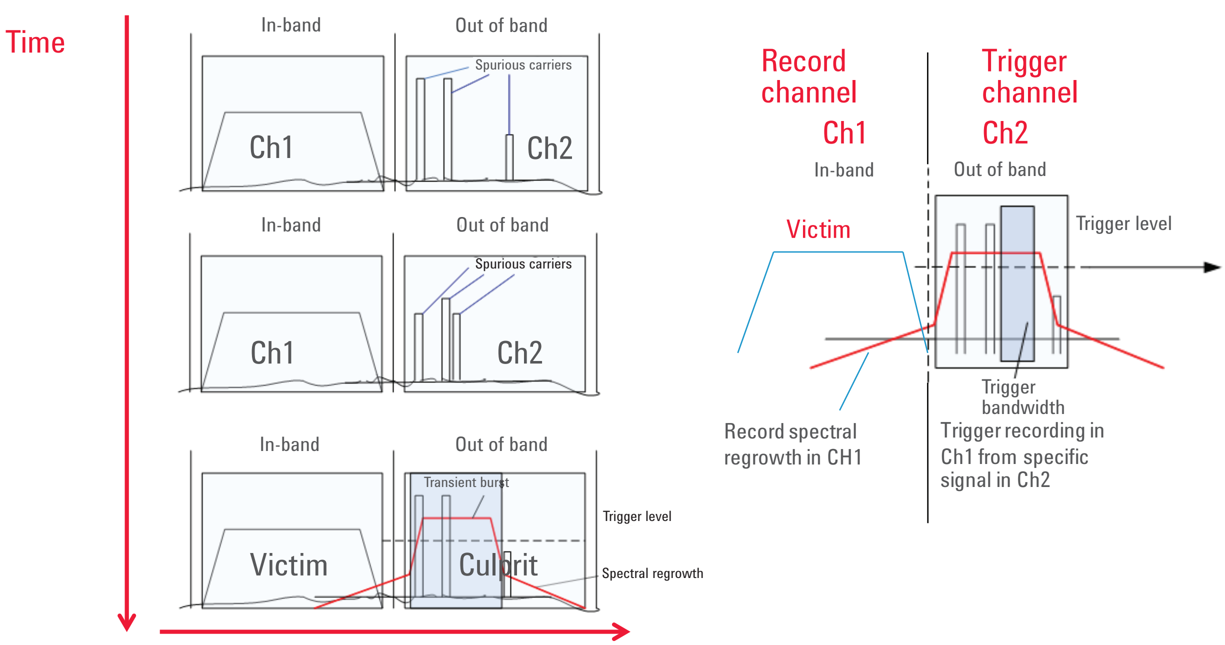

Figure 13. In this example, an intermittent out-of-band signal leaks into the victim channel.

Resolving RF Interference Problems with a Structured Process (continued)

Application examples (continued)

In-Band Interference Test

In Figure 14, an interferer is suspected of intermittently degrading the victim receiver. In this case, one channel is setup to record. The engineer monitors the active channel using the other receiver. A spectrograph or persistent spectrum can be used to identify the interferer when it appears. Since the recording channel can be configured with many seconds of pre-trigger, it is possible to manually trigger the recording channel and still capture a recording of the interference just as it appeared. This technique can be used when signal clutter is likely to cause false triggering of recordings.

Note that because the monitoring channel is using a normal signal analyzer acquisition mode, there will be gaps in its recorded data. However, this will only be a problem if the interferer signal appears for very short durations (e.g., less than 100 milliseconds). The benefit of this mode is that the engineer can use specific signal events to make the triggering decision.

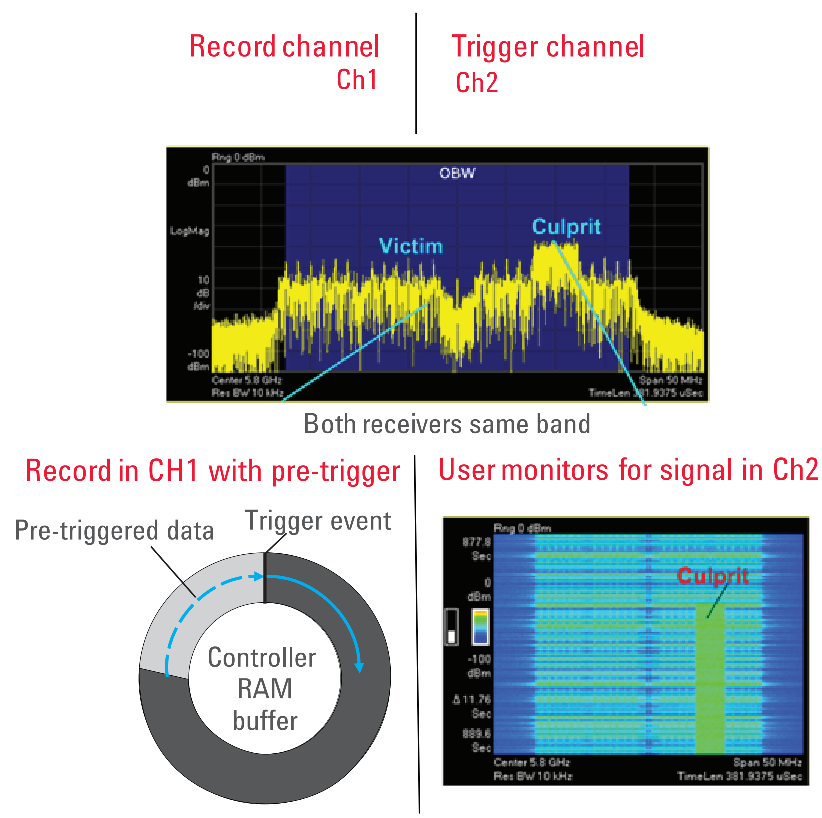

Figure 14. For in-band interference test, the engineer can use user-operated trigger on one channel, while recording on the other.

Application examples (continued)

Cognitive-Radio Dynamic Spectrum Access (DSA) Validation

A goal of dynamic spectrum access is to increase spectrum utilization without causing interference. Consider a scenario in which the cognitive radio starts transmitting with some OFDMA carrier allocation (frequency) and at some point in time detects an interferer. To maintain its data throughput with another radio or base station, the cognitive radio may alter its subcarrier allocation to utilize other whitespace available within the radio's policy. In this case, a wide bandwidth recording capability is useful for measuring multiple radio channels simultaneously.

Consider the cognitive radio application in Figure 15. When testing the frequency hop algorithms or responding to RF channel performance changes by modifying the signal constellation it is useful to record just the signal transitions. The frequency bands used by the cognitive radio are highlighted by the arrows running through the figure's white rectangular blocks. When an interferer appears in band, the response of the radio to the interferer is recorded. Likewise, when a wireless channel deteriorates, the radio's response is recorded. These types of measurements can be easily handled by a multi-channel recording system.

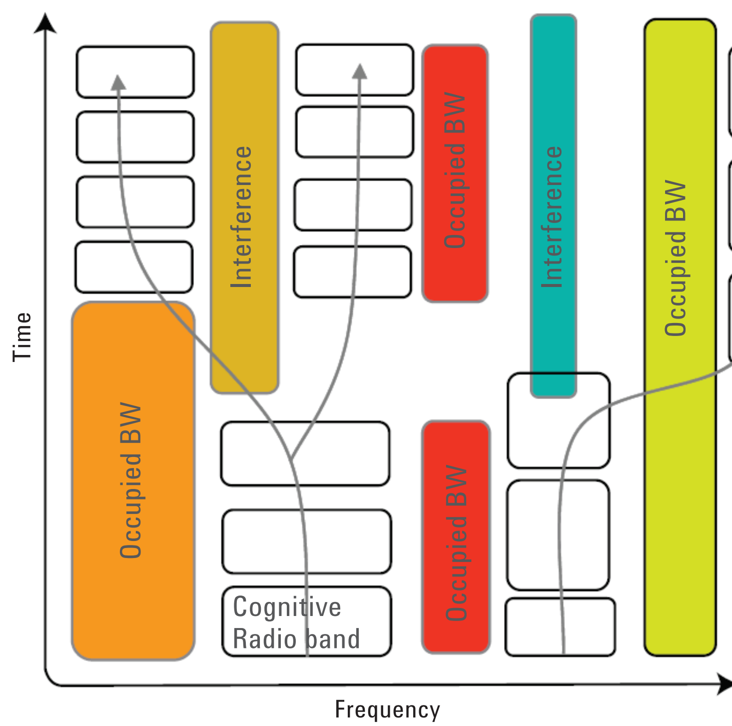

Figure 15. In cognitive radio applications, a multi-channel recording system can be used to trigger the recording from a specific interference event and record that all transmission bands and channel hops are correct.

Application examples (continued)

Dynamic Frequency Selection (DFS)/RADAR Detection

Consider the scenario in Figure 16. DFS is a communications technique whereby transmitters actively 'listen' to the RF environment and dynamically choose transmit channels based on the environment characteristics. The goal for transmitters employing DFS is to transmit on the 'best' channel (typically the channel with the lowest level of detectable RF energy).

WLAN 802.11 access points operating in the 5-GHz band are required to detect and then avoid military and weather RADARS sharing the same frequency channels. When the 802.11 access point detects a RADAR pulse it must stop transmitting and find an alternative channel to transmit on. With a wideband multi-channel recording solution, RADAR profiles can be run and RF data recorded. The data can then be analyzed offline.

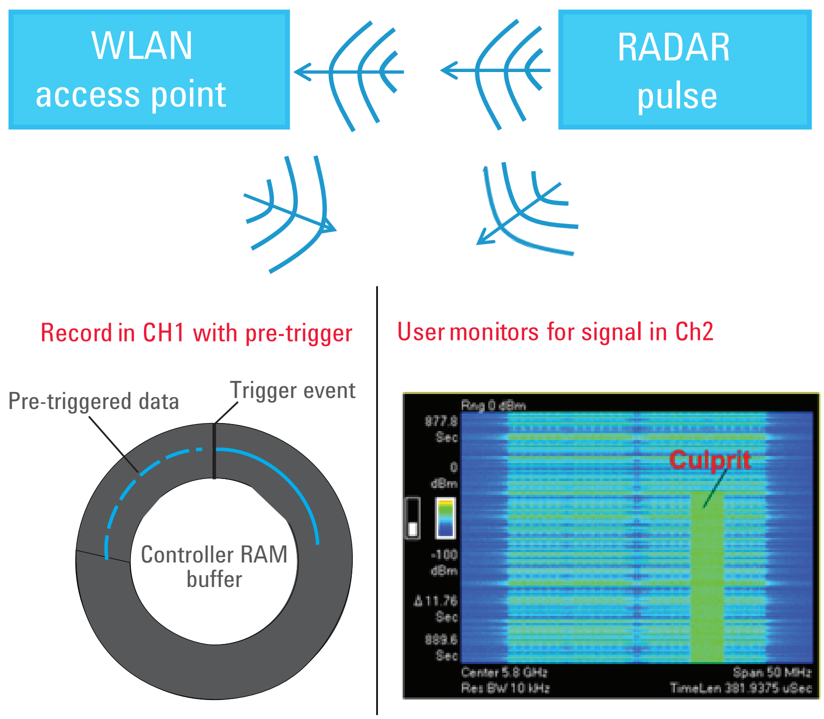

Figure 16. A wideband multi-channel recording solution is well suited for DFS and RADAR detection.

When very large recordings of captured data must be searched for culprits, a powerful signal analysis tool like Spectro-X from Keysight's solutions partner, X-COM Systems, may prove especially helpful. Using the software, searches can be made for carriers, standards based communications signals or custom searches based on any unknown signal found in the record. Some of the software's key capabilities include the ability to pre-process large data sets and locate suspect signals. Spectro-X includes search engines to identify and "fingerprint" waveforms, as well as a "clip and save" capability for replay into the 89600 vector signal analysis (VSA) software.

For more information on Spectro-X and other X-COM solutions, please see Application Note 5991-0768EN, "Streaming, Analysis and Playback of RF Interference Signals in Aerospace and Defense Applications."

Conclusion

Resolving RF interference problems in complex RF environments is challenging. With gapless recording; however, engineers can now measure data continuously over long durations and ensure the capture of all RF events of interest when they occur. A wideband recording system modified for gapless capture, especially one that's dual channel, can be very effective in characterizing system interference in RF environments. Utilizing the recording system in a systematic, structured flow provides an efficient way to find, record and analyze target signals. Coupling the system with powerful search tools reduces the burden of searching long recordings for interferer signals, while signal analysis software provides engineers with key insight into the characteristics of the interferer and its effects on the victim signal in select data obtained during gapless recording. Such functionality is crucial in today's commercial wireless and EW applications where interference-related issues are highly problematic.

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