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# The Ins and Outs of Microwave Signal Capture and Playback
## Article Reprint

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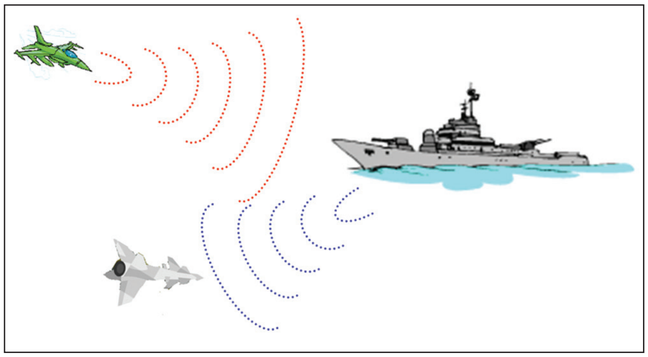
# The Ins and Outs of Microwave Signal Capture and Playback

The capture and playback of microwave signals has a multitude of applications in the evaluation of communications, radar and electronic warfare systems. The stimulus and analysis requirements of system level testing differs from the functional testing of the various sub-systems, boards and components that make up the system for a number of reasons. For instance, these types of systems are becoming increasingly multi-role and multi-mode in nature, perhaps even performing multiple functions at the same time. The systems will need to automatically reconfigure themselves depending on the stimulus at one or more of their sensor ports. So, a benign or static test stimulus that may be sufficient to verify a lower level subsystem will not be sufficient to fully exercise the dynamic operation of the full system under all or even a few of its operating conditions.

To provide an environment adequate for functional evaluation of the system, the test stimulus must be long and unique – in other words, a complete, non-repetitive scenario. The issue is that these systems may internally operate in the realm of microwave frequencies and nanoseconds of time, but the environment in which the system lives is governed by real world events that can take seconds, minutes or even hours to unfold. In order to analyze or generate the scenario, the signal must be captured and/or played back at a sample rate that can recreate the highest frequency element



▲ *Fig. 1 The reflected waveform is unique and changing at the receiver antenna during the entire flight.*

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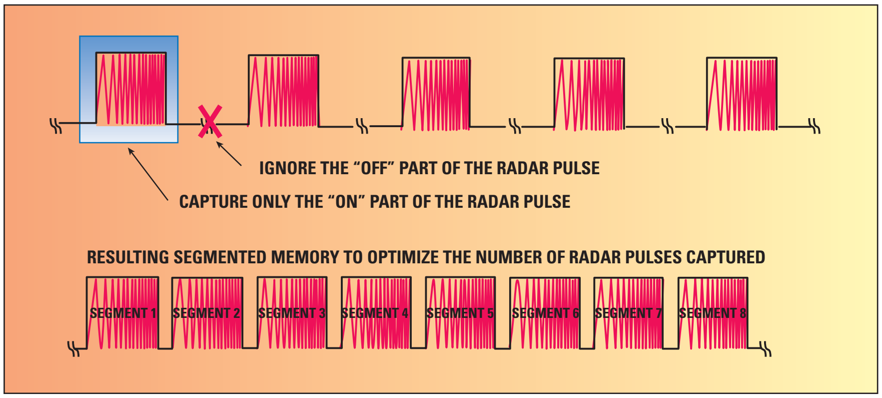


▲ *Fig. 2 Segmented capture of a long pulse train.*

(usually the carrier) and the slowest changing or rarest event the system encounters.

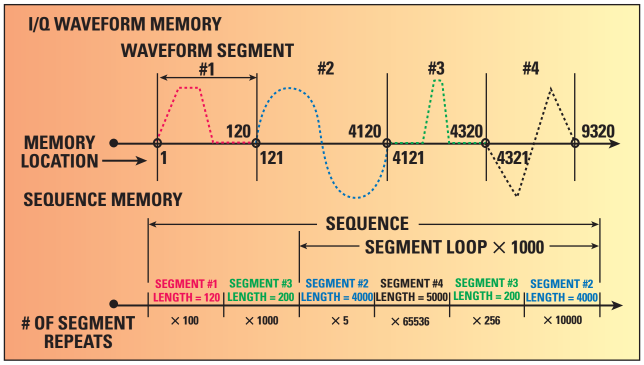
For example, consider the flight of a radar guided missile as illustrated in ***Figure 1***. The signal at the receiver of the missile will be constantly changing from the time it is launched to the time it reaches its target. It may begin in a bi-static mode, where the radar signal is transmitted at a certain frequency from the launching platform, like a fighter jet. During the flight, the missile and target will be accelerating or decelerating, putting a Doppler frequency shift on the carrier at a relatively low rate of change. The Radar Cross Section (RCS) changes constantly as the relative position of the missile and target changes. As the missile approaches the target, the pulses become more closely spaced. The mode of the radar may change to maintain optimal tracking of the target through changes in the pulse repetition frequency (PRF) and pattern. There will probably be an attempt to jam the signal. Finally, the radar seeker in the missile may take over at a different carrier frequency and PRF.

This requires a very deep memory in order to store all the samples needed to capture or playback this type of scenario. For instance, if the radar operates in X-Band at 10 GHz, a sample rate of approximately 25 GS/s (GigaSamples per second) will be required (Nyquist frequency plus some margin) to accurately capture the signal. For the discussion here, a sample consists of a 32-bit I and Q sample pair. So a memory depth of 2 GS will only hold 80 ms of data at this rate. Fortunately, there are methods for optimizing the use of memory during capture and playback.

## SEGMENTING AND SEQUENCING FOR CAPTURE AND PLAYBACK

When performing measurements on pulsed radar signals, capture and analysis of a large number of pulses is often required. For example, the Agilent 90000X oscilloscope has a deep capture depth of 2 GS. This is the same depth that was used in the example above. The amount of data in terms of time, of course, depends on the sample rate selected.

Segmented memory can further optimize the number of radar pulses that can be captured and analyzed with the available oscilloscope memory. Essentially, it enables the user to zoom in on a pulse and capture only the "ON" portion of the pulse, while ignoring the "OFF" portion of the pulse as illustrated in ***Figure 2***. This helps to optimize memory usage and maximizes the number of pulses that can be captured with the 2 GS of physical memory.



▲ *Fig. 3 Example arrangement of segments in a loop and sequence.*

Many arbitrary waveform generators (AWG) feature a similar sample memory optimization capability. This is termed segmenting and sequencing. Playback of stored waveforms can be defined in a way which effectively "multiplies" the use of existing memory. This multiplication effect is especially apparent for waveforms with significant "OFF" time and repetitions. For example, pulse waveforms with low duty factors need only to define the unique "ON" time plus some small portion of the "OFF" time as separate segments in memory. The single "OFF" segment is looped and replayed as needed.

Many different waveform segments can be stored in the AWG waveform memory. Sequences are formed, using a contiguous series of segments. Because each segment has a specified start and stop address, sequence play is continuous and without gaps, when played from one segment to the next. Multiple segments can be grouped and looped for even greater memory compression. This waveform scenario construction is illustrated in ***Figure 3***.

## APPLICATIONS FOR CAPTURE AND PLAYBACK

In addition to the radar guided missile example, there are broad requirements in the aerospace and defense community for capture and playback of long, unique, non-repeating signals. One application example is interference testing. Interference is an undesired emitter, which could reduce or block the sensitivity of a receiver. Interfering emitters are often unpredictable: one does not know when they will occur, where in the spectrum they will appear or how long they will last. In order to fully understand the true nature of these interfering signals, many seconds, minutes or even hours of capture time may be required to guarantee that an event is captured.

What may be the most challenging application of signal capture and playback is radar target simulation. Here, the target return is coherent with the transmit pulse radar because the transmit pulse is captured and "immediately" played back to the radar receiver, with some fixed and perhaps added latency while maintaining a constant phase. Systems dedicated to this function are termed Digital RF Memories (DRFM). Due to the relatively narrow use cases (radar target simulation and deceptive radar jamming) and custom nature of these DRFM systems, they are generally quite expensive. No solution using general purpose, off the shelf instruments currently exists. The requirements for such a capability include: a known, fixed signal latency through the system and the ability to act on the signal as it passes through the system (e.g., adding simulated Doppler).

For applications such as these, an extremely large amount of memory is needed. The ability to capture and perhaps playback without gaps at a very high data rate is also needed. So let's now discuss the concept of waveform streaming.

## WAVEFORM STREAMING

Streaming is a flow of data that can be I and Q sample data, symbols, bits, waveform description, etc. The stream can last for an indeterminate, although generally finite, period of time, so there is not necessarily information about when the stream will end. The average data rate at the destination of the data is the same as at the source.

There are three basic use cases for streaming capture and playback of RF and microwave signals:

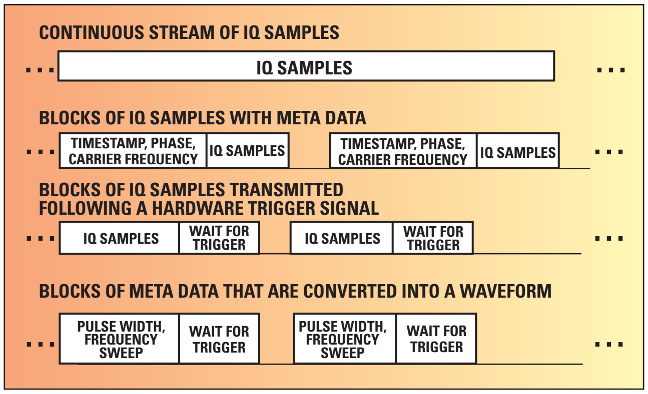
- Capture or playback of long waveforms to or from an extremely deep memory, which could be disk array of many Terabytes set up in a RAID configuration for faster write speeds.
- Waveform to be defined dynamically during playback, based on the system's reaction to the current waveform. The next waveform segment to play is selected just prior to the current segment completing or it is created mathematically at run-time.
- Streaming allows a digitizer to capture a signal, optionally process it in a DSP and re-transmit it from an AWG in real time, as described in the DRFM application example above.

There are many different ways and types of data that can be utilized to stream a waveform in addition to just a continuous stream of I and Q samples. ***Figure 4*** shows the possible data transmissions over the streaming interface, which define a waveform. Meta data can be employed with waveform description data. Triggering enables control over the timing of the waveform.

## THE STREAMING INTERFACE

The link or interface between the source of the data and its destination in a streaming configuration is, of course, critical for the rate that samples can be captured and the bandwidth of the signal that can be streamed. There are a few possibilities here, but one most promising is PCI Express (PCIe).

PCIe is a serial high speed interconnect, which replaced legacy bus-based PCI and PCI-X technologies, and is now migrating from desktop to embedded applications. PCI-Express operates more like a network than a bus. It utilizes a point-to-point topology, with separate serial links connecting peripherals to the processor. Data rates for PCIe 1.x ranges from 250 MB/s per lane to 4 GB/s using up to 16 lanes in each direction. The latest release version of the standard (3.0) can support 1 GB/s per lane to 16 GB/s for 16 lanes.



▲ *Fig. 4 Possible transmission over the streaming interface.*

What kind of signal bandwidths can be accommodated in streaming over PCIe? With a data rate of 1 GB/s, this equates to 250 MS/s (32 bit I and Q pairs) and a capture/playback modulation bandwidth of 200 MHz. As can be seen from the evolution of PCIe, much wider bandwidths are possible. One difficulty might lie in the development of an interface driver to unlock the potential of the PCIe architecture and handle the flood of data over multiple lanes.

## CONCLUSION

Streaming capture and playback of microwave signals is necessary for the development of advanced systems that operate in multiple modes, in a constantly changing environment. Solutions using off-the-shelf equipment have been lagging for this need, making it necessary for some to develop expensive custom solutions. It appears now that general purpose instrument manufacturers are beginning to implement the needed architectural features to stream waveforms at a high enough sample rate to address today's wide bandwidth applications. This is good news for our equipment budgets. ■

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