APPLICATION NOTE

Radar and EMSO Subsystem Test

Part 1: Signal source essentials

KEYSIGHT

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The evolution from purely analog designs to hybrid analog/digital designs continues to drive advances in radar system capability and performance. Frequencies reach higher as signals become increasingly agile. Signal formats and modulation schemes—pulsed and otherwise—continue to evolve in complexity, demanding wider bandwidth. Advanced digital signal processing (DSP) techniques are used to disguise system operation and avoid jamming. Architectures such as active electronically steered arrays (AESA) rely on advanced materials such as gallium nitride (GaN) to implement phased-array antennas that enhance the performance of beamforming and beam steering.

This application note starts with the basics of radar and EW transmitters and receivers and the performance of different pulse-compression schemes. It covers how to choose the right instrument to generate signals to test components, receivers, and systems, as well as those needed for effective EW simulation.

Radar Basics

Radar systems essentially gather information about a target — location, speed, direction, shape, or identity by processing reflected radio frequency (RF) or microwave signals, or a transmitted response in the case of secondary radars.

In most implementations, a radar system generates a pulsed-RF or pulsed-microwave signal, beams it toward the target in question, and collects it by the same antenna that transmitted the signal. The radar range equation describes this basic process. The signal power at the radar receiver is directly proportional to the transmitted power, the antenna gain (or aperture size), and the radar cross-section (RCS) (i.e., the degree to which a target reflects the radar signal).

Perhaps more significantly, it is indirectly proportional to the fourth power of the distance to the target. Given the large attenuation that occurs while the signal is traveling to and from the target, high power is very desirable; however, it is also difficult due to practical problems such as heat, voltage breakdown, dynamic power requirements, system size, and, of course, cost.

Radar Signal Parameters

Every radar transmission starts with a known carrier signal, and today these typically operate at microwave or millimeter-wave frequencies. The carrier may be coded mainly because changes in the return signal provide a more accurate measurement of the distance to the target. In most cases, pulse modulation is also applied because controlling pulse duration, repetition rate, and power enhances the resolution and maximum range of the radar system. Radar signals can be defined in the time and frequency domains and in terms of Pulse Descriptor Words (PDW) that are defined by amplitude, frequency, and timing information. Engineers use PDWs to efficiently and digitally store and stream radar signals.

Optimizing Pulse Parameters

The characteristics of a pulsed radar signal largely determine the performance and capability of the system. Pulse parameters such as power, repetition rate, width, and modulation are traded off to obtain the optimum combination for a given application (Figure 1). Pulse power directly affects the maximum range of detection. Droop across the pulse top indicates instability in the output power.

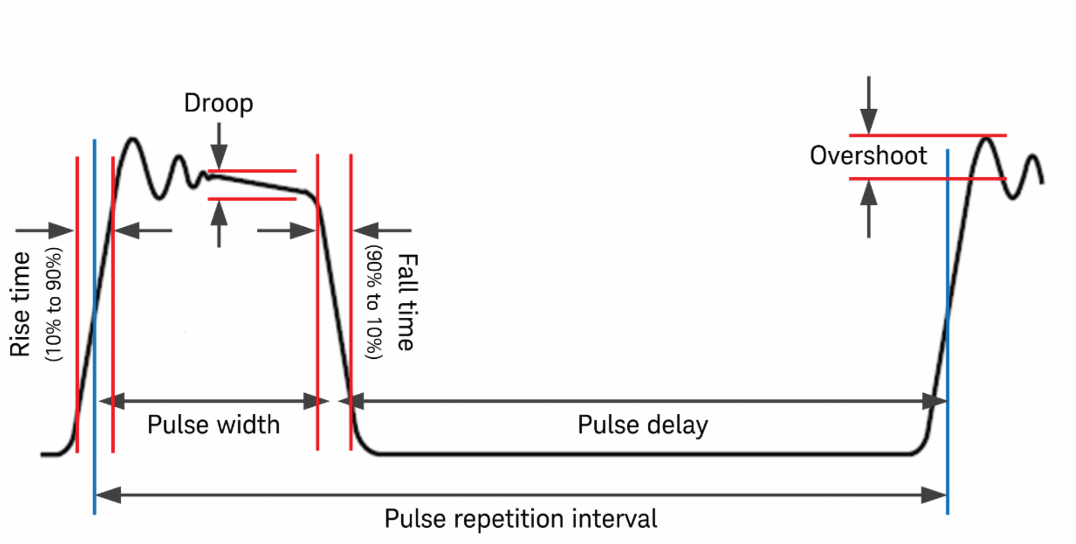


Figure 1. The essential characteristics of real-world pulses affect the performance of the radar system.

The time between pulses—the pulse-repetition interval (PRI)—determines the maximum unambiguous range to the target; pulse repetition frequency (PRF) is the inverse of PRI. The duration of the pulse, or the pulse width, determines the spatial resolution of the radar: pulses must be shorter than the time it takes for the signal to travel between the target details; otherwise, the pulses overlap in the receiver.

Together, pulse width and shape determine the spectrum of the radar signal. Decreasing the pulse width increases signal bandwidth; however, wider system bandwidth results in higher receiver noise for a given amount of power and reduced sensitivity. Also, the pulse spectrum may exceed regulated frequency allotments if the pulse is too short.

The shape can be the familiar trapezoidal pulse with rapid but controlled rise and fall times. It may also be an alternative shape, such as Gaussian or raised-cosine. Because the pulse shape can determine the signal bandwidth and affect the detection and identification of targets, it is chosen to suit the application's requirements.

Short pulses with a low repetition rate maximize resolution and unambiguous range, and high pulse power maximizes the radar's range. There are, however, practical limitations in generating short, high-power pulses. For example, higher peak power will shorten the life of tubes used in high-power amplifier designs. This conundrum would be a barrier to increasing radar performance if radar technology stopped here. However, engineers use complex waveforms and pulse-compression techniques to significantly mitigate the power limitation on pulse width.

Adding Pulse Compression

Compression techniques allow relatively long RF pulses to be used without sacrificing range or resolution. The key to pulse compression is energy: using a longer pulse reduces the peak power of the transmitted pulse but maintains the same average pulse energy. The received pulse is compressed using a match-correlation filter, producing a shorter pulse of greater peak power and narrower width.

From this, a pulse-compression radar realizes many of the benefits of a short pulse: improved resolution and accuracy; reduced clutter; better target classification; and greater tolerance to some electronic warfare (EW) and jamming techniques. One area that does not improve is minimum range performance: the long transmitter pulse may obscure targets too close to the radar.

Compressing the pulse with a matched filter is achieved by modulating the RF pulse. You can accomplish this digitally using the cross-correlation function to compare the received and transmitted pulses. The sampled receive signal is repeatedly time-shifted, fast Fourier transformed, and multiplied by the conjugate of the Fourier transform of the sampled transmit signal (or a replica).

The output of the cross-correlation function is proportional to the time-shifted match of the two signals. A spike in the cross-correlation function or matching filter output occurs when the two signals are aligned. This spike is the radar return signal and maybe 1000 times shorter in duration than the transmitted pulse.

Even if two or more transmitted pulses overlap in the receiver, the sharp rise in output occurs only when each pulse is aligned with the transmit pulse. This restores the separation between the received pulses and, with it, the range resolution. To reduce the time-domain sidelobes created during the cross-correlation process, the received waveform can be processed with a windowing function of Hamming shape or similar.

Ideally, the correlation between the received and transmitted signals would be high only when the transmitted and received signals are exactly aligned. Many modulation techniques can be used to achieve this goal: linear FM sweep, binary phase coding (e.g., Barker codes), or polyphase codes (e.g., Costas codes).

Accounting for Doppler Effects

Most targets of interest are moving. This causes the frequency of the returned signal to shift higher as the target moves toward the radar and lower as the target moves away. Unfortunately, this Doppler frequency shift can reduce the sensitivity of location detection.

As mentioned above, the output of the cross-correlation filter is proportional to the match between the received and transmitted signals. If the received signal is slightly lower or higher in frequency, then the filter output is somewhat lower.

For a simple pulse, the filter response follows the familiar sin(x)/x shape as a function of Doppler frequency. In extreme cases, the frequency of the received signal may shift far enough to correlate with a sidelobe of the transmit signal.

Note that short pulses have a relatively wide initial lobe in the sin(x)/x response and tend to be “Doppler tolerant” compared to longer pulses. In pulse compression schemes such as Barker coding, the matching-filter output drops off much faster than the sin(x)/x of the simple pulse, making them “Doppler intolerant.”

Doppler shifts in linear FM pulses can create an error in the location information because the highest cross-correlation occurs where the swept frequencies in the received pulse are best aligned with the swept frequencies in the transmit pulse. This offset is directly proportional to the Doppler shift.

Bringing it all Together

Graphs called ambiguity diagrams illustrate the performance of different pulse-compression schemes as a function of pulse width and Doppler frequency shift (Figure 2). Even though Doppler shift can reduce detector sensitivity and cause errors in time alignment, it also provides important information about the target.

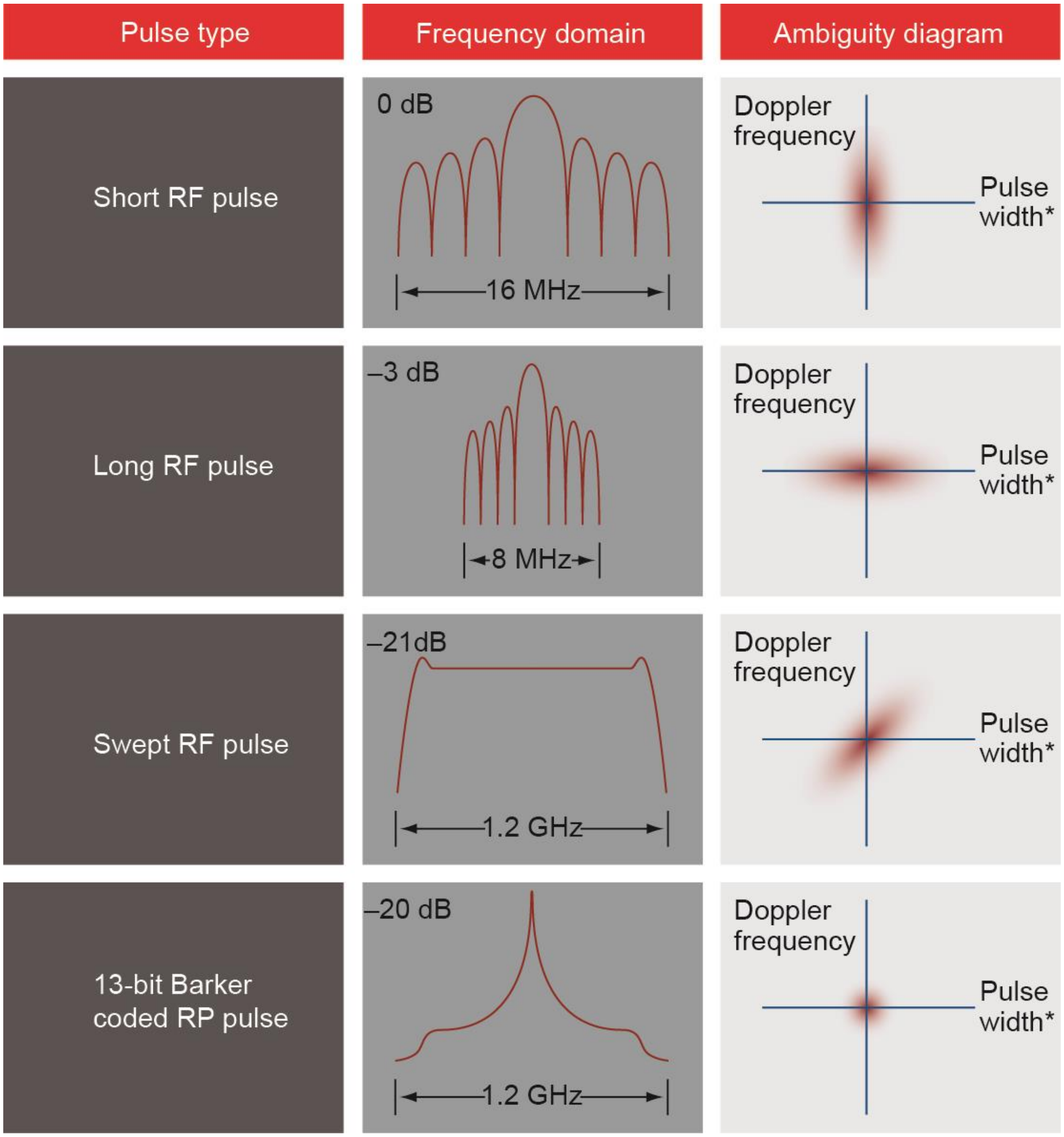


Figure 2. The ambiguity diagrams illustrate location accuracy versus Doppler accuracy. This figure shows relative ambiguity diagrams for different types of radar pulses.

*Note: In the ambiguity diagram, “pulse width” refers to the width at the output of the radar detector.

Signal Generator Essentials

Engineers use signal generators to test components, receivers, and systems for various applications throughout the product development cycle. The output signal can be as simple as a continuous wave (CW) or complex like a digitally modulated signal. Figures 3 and 4 show common signal generator use cases for component and receiver tests.

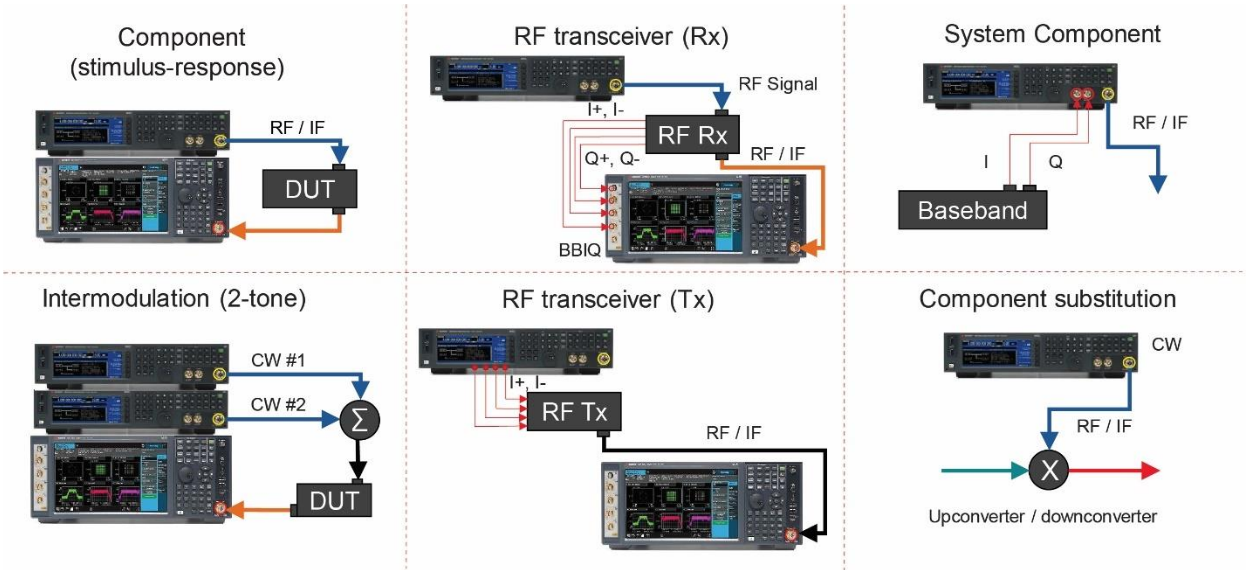


Figure 3. Signal generator use cases for component characteristic tests or a system component

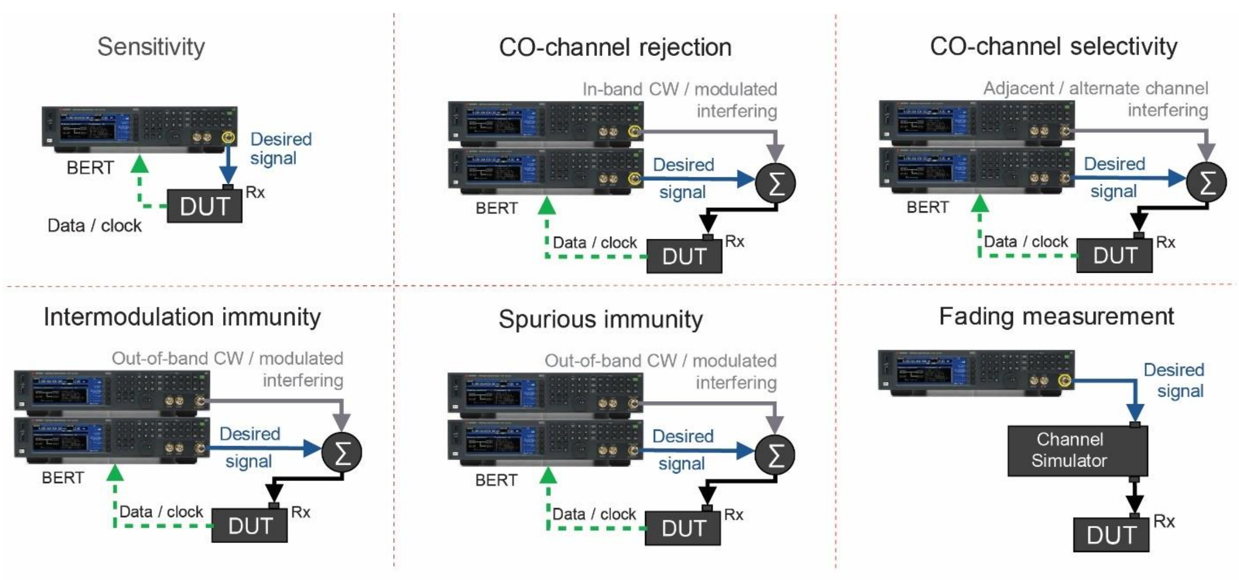


Figure 4. Signal generator use case for receiver sensitivity tests

Signal generators can be classified based on their form factor and capabilities.

Form Factor: Benchtop or Modular?

The most common signal generator form factor is the benchtop. We typically see these boxed instruments on benches and in racks. Benchtop signal generators are well-suited for R&D, where engineers use the front panel controls to analyze and troubleshoot devices.

The PXIe modular form factor signal generators are compact instruments housed in a PXIe chassis and controlled using a PC. Several PXIe signal generators can be placed in a single chassis, making them ideal for applications that require multi-channel measurement capabilities, fast measurement speed, and a small footprint. A PXIe signal generator often uses the same software applications as a benchtop signal generator, providing measurement consistency and compatibility from product development to manufacturing and support.

Figure 5. Benchtop and PXI modular signal generator

Capabilities: Analog, Vector, and Agile Signal Generators

Analog signal generators supply sinusoidal continuous wave (CW) signals with the option to add AM, FM, ΦM, and pulse modulation. The maximum frequency range for analog signal generators spans from RF to microwave. Most generators feature step/list sweep modes for passive device characterization or calibration.

Vector signal generators (VSG), a more capable class of signal generators, enable complex digital modulation schemes. VSGs have a built-in quadrature (also called IQ) modulator to generate complex modulation formats such as quadrature phase-shift keying (QPSK) and 1024 quadrature amplitude modulation (QAM). When combined with an IQ baseband generator, virtually any signal can be emulated and transmitted within the information bandwidth supported by the system.

Optimized for speed, agile signal generators can quickly change frequency, amplitude, and phase of the signal. They also have the unique capability to be phase coherent at all frequencies and at all times. This attribute and extensive pulse modulation and wideband chirp capabilities make them ideal for electronic warfare and radar applications.

Overview of Key Specifications

To select the right signal generator for your project, you'll need to understand its performance specifications. Specifications tell you about the capability of your signal generator. Let's explore major specifications: frequency, amplitude, and spectral purity performance.

Frequency specifications

The frequency specification defines the range, resolution, accuracy, and switching speed of a signal generator.

- **Range** — the maximum and minimum output frequencies your signal generator can output.
- **Resolution** — the smallest frequency change.
- **Accuracy** — how close the source's output frequency is to the set frequency.
- **Switching** — how fast the output settles down to the desired frequency.

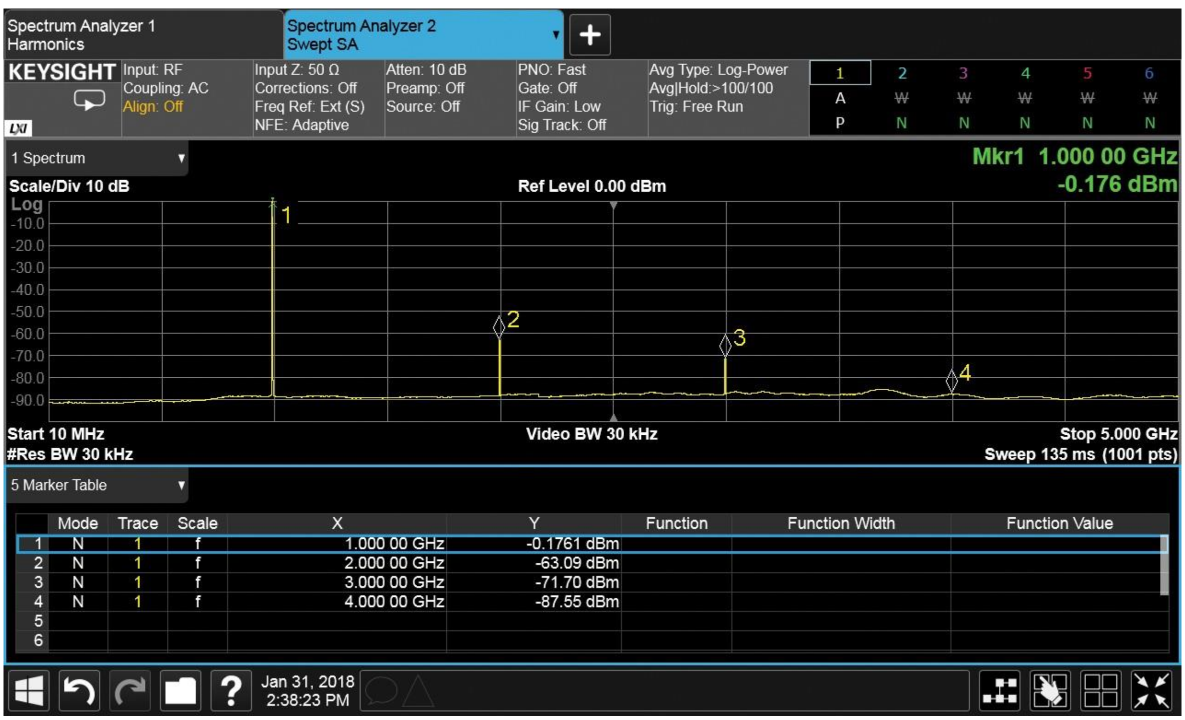


Figure 6. Spectrum analysis with frequency and amplitude readouts

Amplitude specifications

Amplitude specifications include range, resolution, and switching speed.

- **Range** — the difference between the maximum and minimum output power capability of the signal generator. The signal generator's output attenuator design determines its range. The output attenuator allows the signal generator to produce extremely small signals used to test a receiver's sensitivity.
- **Resolution** — the smallest possible power increment.
- **Switching speed** — how fast the source can change from one power level to the next.

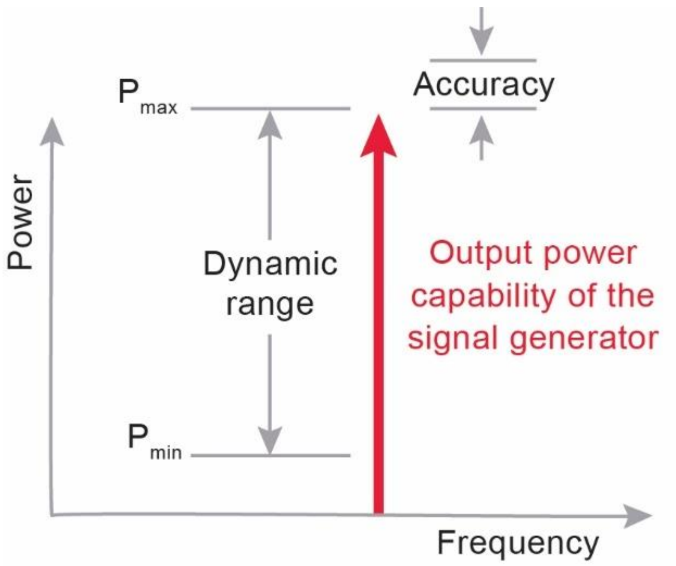


Figure 7. Power output range and accuracy

Spectral purity

Spectral purity is the inherent stability of a signal. A perfect signal generator will generate a sinusoidal wave at a single frequency without the presence of noise. However, signal generators consist of non-ideal components which introduce noise and distortion. The specifications associated with spectral purity are often the most difficult to understand. These specifications include phase noise, harmonics, and spurs, as shown in Figure 8.

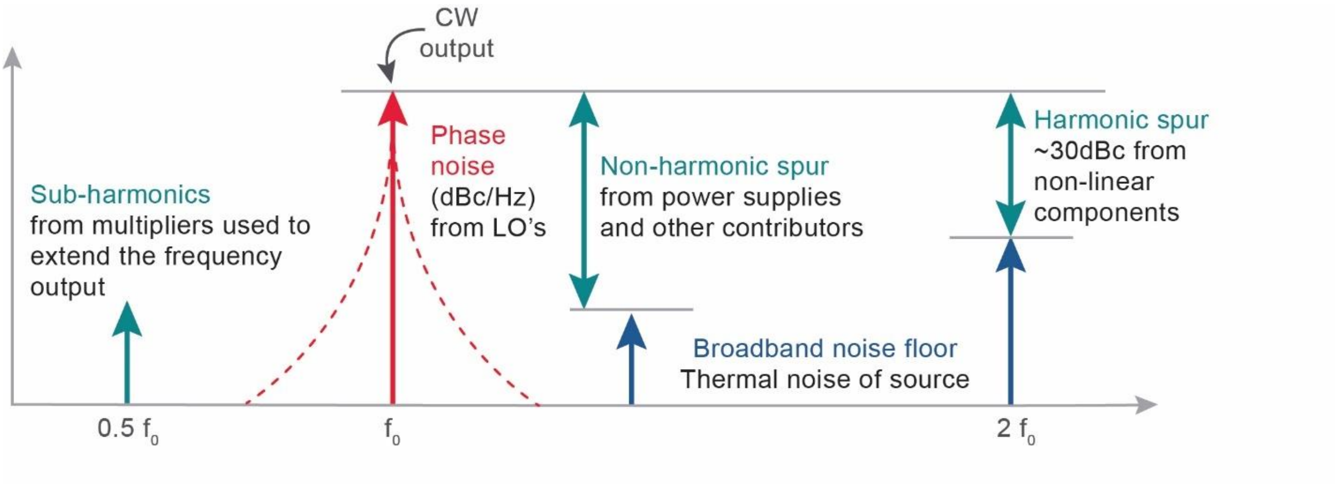


Figure 8. Various non-ideal spectral components

- **Phase noise** — a frequency-domain view of the noise spectrum around the oscillator signal. It describes the frequency stability of an oscillator.
- **Harmonics** — integer multiples of the sinusoidal fundamental frequency output. These harmonics are caused by the non-linear characteristics of components used in the signal generator.
- **Spurs** — non-random or deterministic signals created from mixing and dividing signals to get the carrier frequency. These signals may be harmonically or non-harmonically related to the carrier.

Ultra-Wideband Arbitrary Waveform Generators (AWGs)

Arbitrary waveform generators can vary on sample rate and resolution, and those two parameters are often inversely related (Figure 9). AWGs with higher sample rates will have lower resolutions than those with lower sample rates and vice-versa. AWGs can simulate high-density radar signals and communications signals within their bandwidths.

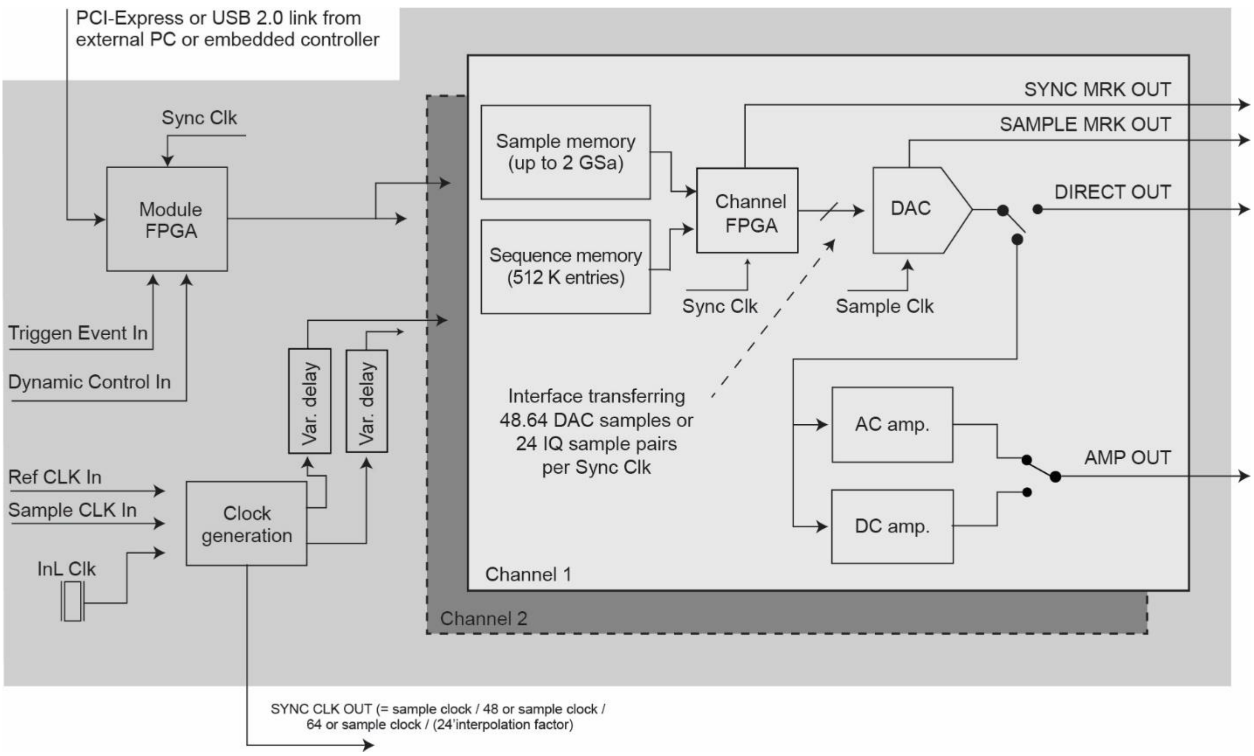


Figure 9. Modern Arbitrary Waveform Generators are comprised of much more than DACs. Such new capabilities involve memory sequencing, clock sharing for synchronization, and different output paths to optimize signals depending on the application. Shown here is the block diagram for the high-resolution M8190A Arbitrary Waveform Generator.

Ultra-wideband AWGs have extremely wide bandwidth, which allows for the generation of single and multiple emitters across wide frequency spans. High-resolution AWGs can output signals with a high dynamic range within narrower bandwidths. Key capabilities include support for simultaneous pulses (pulse-on-pulse) and the ability to modify I/Q data to allow for environmental effects. Multiple channels can also be synchronized for tests requiring multiple coherent channels. In contrast to other source types, ultra-wideband AWGs tend to have lower resolution and dynamic range. They also require a large amount of storage due to their extremely high sample rates. High-resolution AWGs have lower bandwidths and can be upconverted using the appropriate architecture.

a) Baseband generation

b) Direct RF generation in the first nyquist band

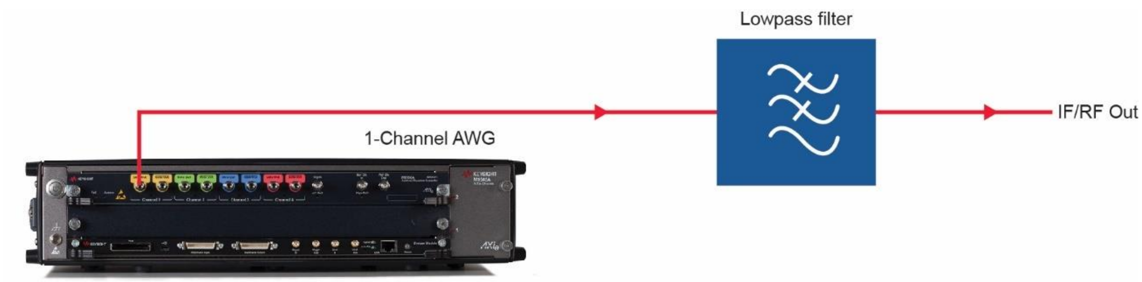


Figure 10. AWGs can generate radar (and any RF) signals following two different basic schemes

Electronic Warfare Signal Generation Technologies and Methods

Productive and efficient engineering of electronic warfare (EW) systems requires the generation of test signals that accurately and repeatedly represent the EW environment. Simulation of multi-emitter environments is vital to ensure realistic testing.

Simulation for these multi-emitter environments traditionally encompasses large, complex, and custom systems during the system qualification and verification stage. These systems are usually not widely available to EW design engineers as R&D test equipment. EW designers working on optimization and pre-qualification are at a disadvantage compared to wireless engineers performing similar tasks. EW engineers often discover the nature and magnitude of performance problems later in the design phase — leading to delays, design rework, and solutions that are not optimal.

Realism and fidelity in multi-emitter environments

Validation and verification of EW systems are heavily dependent on testing with realistic signal environments. Adding high-fidelity emitters for greater signal density creates a realistic EW test environment. In addition, emitter fidelity and density, platform motion, emitter scan patterns, receiver antenna models, the direction of arrival, and multipath and atmospheric models enhance the ability to test EW systems under realistic conditions. The designs for modern EW systems can identify emitters using precise direction finding and pulse parameterization in dense environments of 8 to 10 million pulses per second.

The cost of the test is as important as test realism, as the relationship between cost and test fidelity is exponential. As test equipment becomes more cost-effective and capable, more EW testing can be performed on the ground — in a lab or chamber — rather than in flight. Even though flight testing can add test capability, it does so at a high cost. It is typically done later in the program lifecycle, adding risk and further expense through missed deadlines if the system under test (SUT) fails. It is far better to test early in a lab environment with as much realism as possible, where tests are easily repeated to identify iteratively and resolve issues.

Challenges of simulating multi-emitter environments

The modern spectral environment contains thousands of emitters — radios, wireless devices, and tens to hundreds of radar threats — producing millions of radar pulses per second amidst background signals and noise. Figure 11 shows a general overview of the threat frequency spectrum.

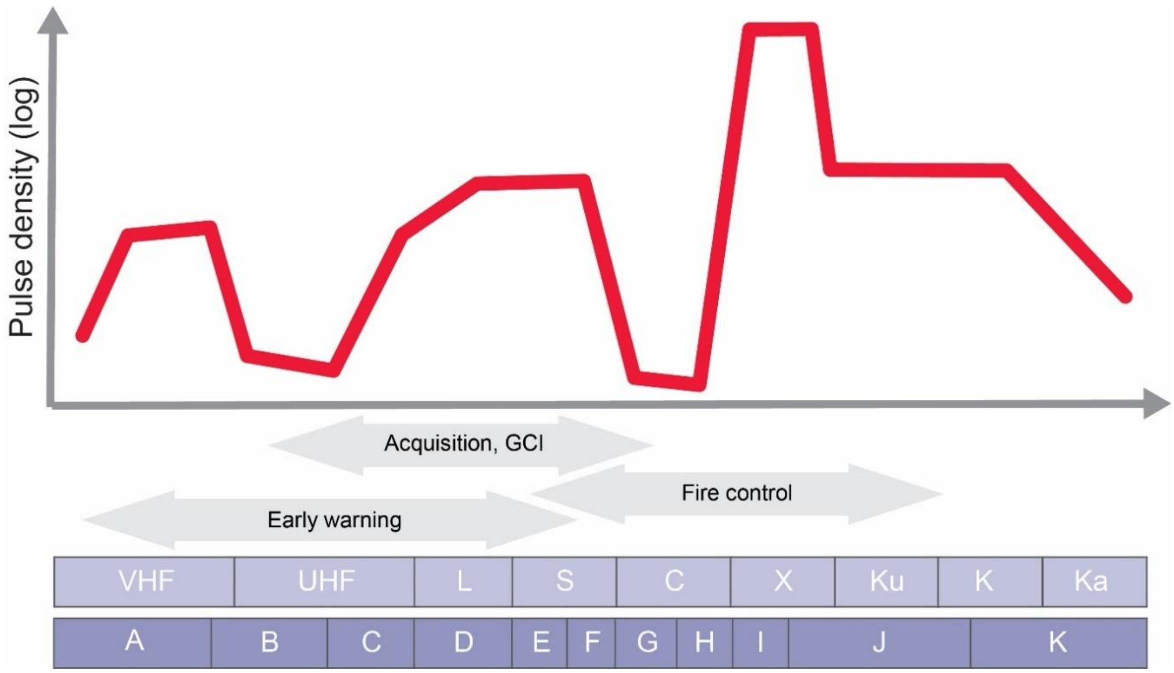


Figure 11. A general representation of the threat density vs. frequency band in a typical operational environment. The full RF/microwave environment would combine the threat and commercial wireless environments.

Simulating this environment is a significant challenge — especially in the design phase when design flexibility and productivity are at their greatest. The situation is quite different from the typical wireless design task, where a single signal generator can produce the required signal, augmented by a second signal generator to add interference or noise.

In EW design, the multiplicity and density of the environment — and often the bandwidth — make it impractical to use a single source or a small number of sources to simulate a single emitter or a small number of emitters. Cost, space, and complexity considerations rule out these approaches.

The only practical solution is to simulate many emitters with a single source and to employ multiple sources — each typically simulating many emitters — when required to produce the needed signal density or to simulate specific phenomena such as angle-of-arrival (AoA).

The ability to simulate multiple emitters at multiple frequencies depends on the following: pulse repetition frequency; duty cycle; the number of emitters; and the capability of the source to switch between frequency, amplitude, and modulation quickly.

A source's agility is a factor in its ability to simulate multiple emitters. Source frequency, phase, and amplitude settling time (whichever is greater) is the transition time between playing one pulse descriptor word (PDW) and the next.

Improvements simplify integration and reduce cost

Simulating more threats to create higher pulse density requires more parallel simulation channels, even if the simulation channel can quickly switch frequency, phase, and amplitude. This is because pulses begin to collide in the time domain as the number of emitters, their PRFs, and their duty cycles grow larger [1]. Pulse that overlap in the time domain must be played out of parallel generators or selectively dropped based on a PDW priority scheme. Unfortunately, the increased realism of a higher-density environment comes at a substantially higher system cost, as shown in Figure 12.

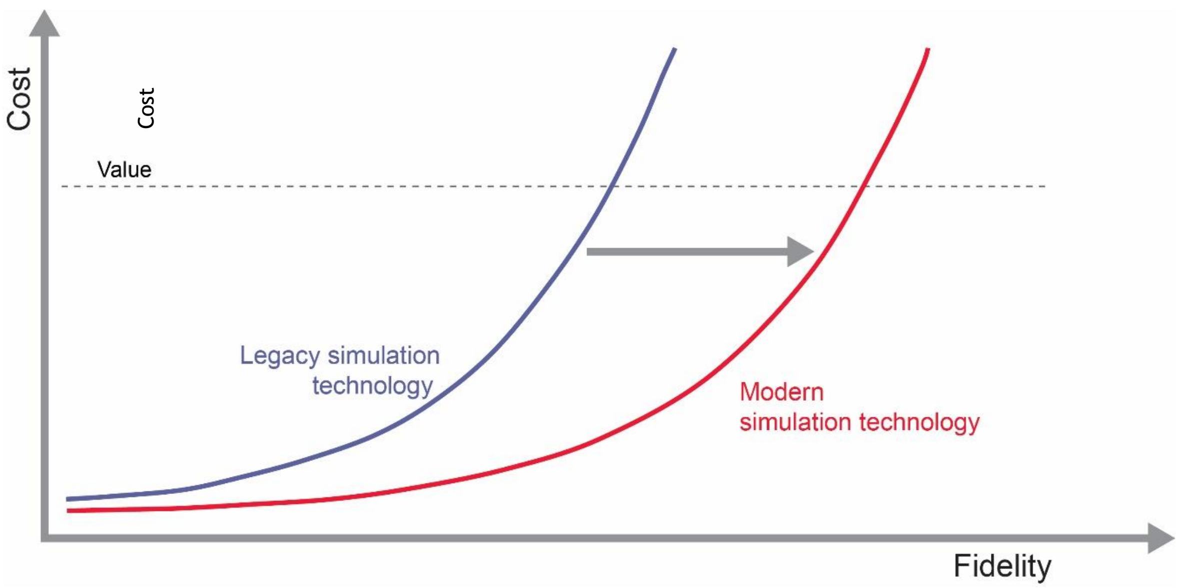


Figure 12. Simulation fidelity and cost increase exponentially. System integrators and evaluators must determine the level of cost versus fidelity to ensure system performance. New simulation technologies enable more simulation realism and fidelity at a lower cost.

In the past, simulations were generally created with a separate component for each emulation function, such as signal generation, modulation/pulsing, attenuation or amplification, and phase shift. The same PDW would be sent to each functional component to provide output on a pulse-to-pulse basis. For instance, a synthesizer would generate the output frequency, while a separate modulator would create pulsed modulation or AM/FM/PM modulation. Amplifiers and attenuators would adjust the signal to the desired output power level. Figure 13 is an example of the system's topology.

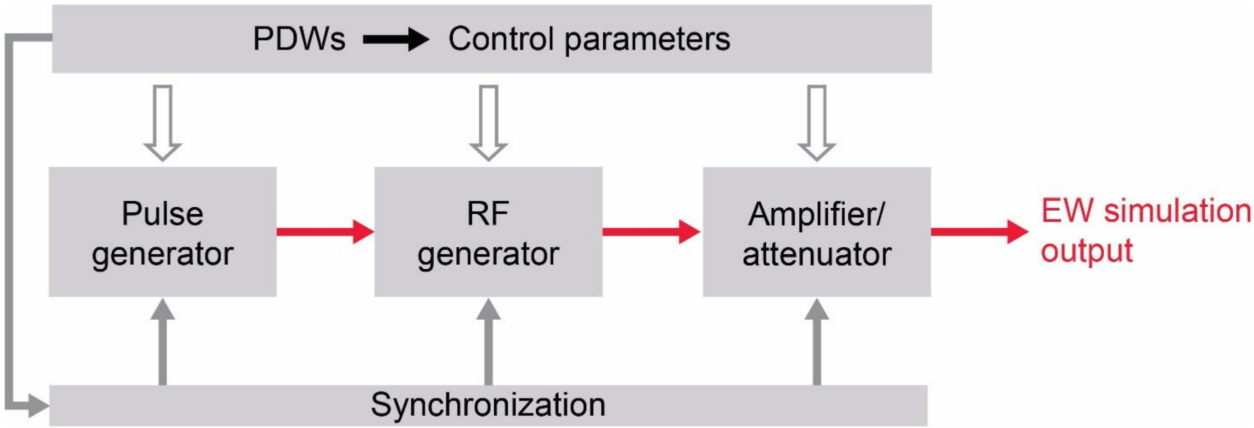


Figure 13. In the traditional approach, PDW control parameters are sent in parallel to multiple functional elements, on a pulse-to-pulse basis, to generate and modify the desired signal. This approach results in a complex system, demanding precise synchronization.

Because multiple functional components are required to produce each output channel, time synchronization is a significant configuration and operational challenge. A wide variety of settling times and latencies must be fully characterized to optimize pulse density by minimizing lockout periods.

This approach can be scaled directly to create multiple coordinated channels, as shown in Figure 14. However, systems configured this way require a large footprint — occupying more rack space — and cost escalates quickly.

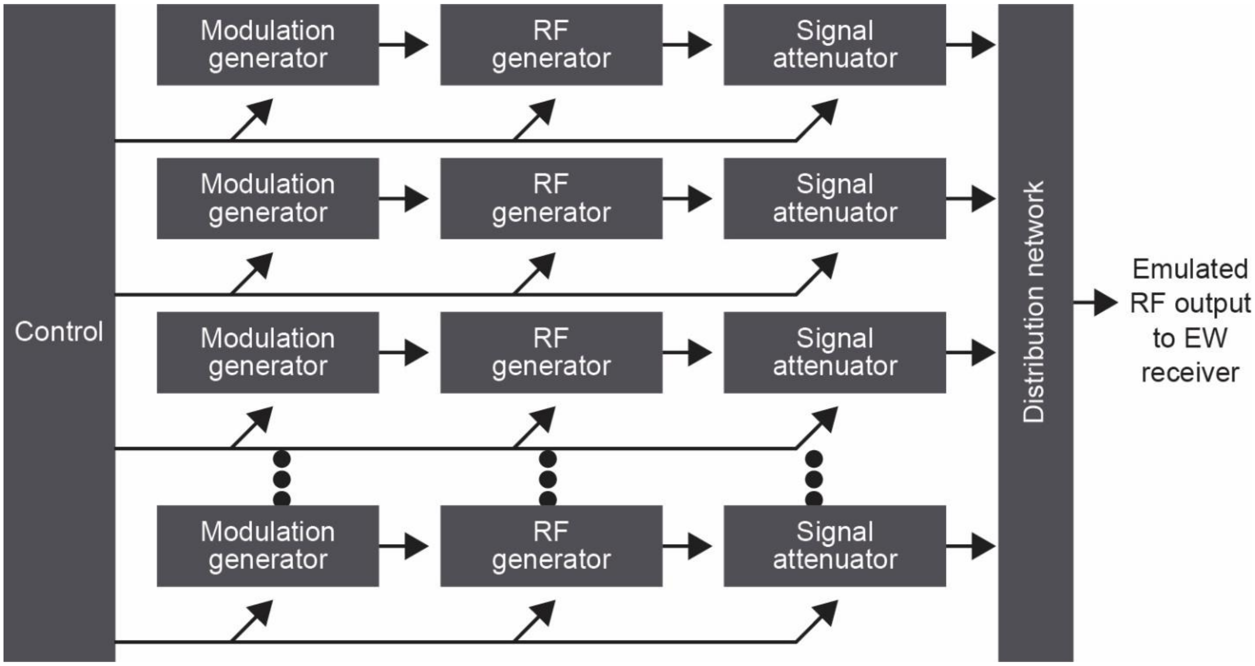


Figure 14. A signal generation approach using separate functional elements can be scaled up to increase pulse density and generate a more realistic environment. The cost and space requirements scale up rapidly as well [2].

The controller in Figure 14 would route PDWs to channels based on emitter parameters, such as frequency, amplitude, pulse repetition frequency, and the availability of each channel to implement the PDW. Because a channel cannot execute the parameters of two different PDWs simultaneously, one could be shunted to a backup channel or dropped according to its priority.

EW receivers must be able to handle 8 to 10 million pulses per second, where most of the pulse density occurs at the X-band. EW receivers must be able to handle pulses arriving at the same time at different frequencies from different angles. Creating pulses that are coincident with one another in the time domain should be a goal of simulation to increase simulation realism.

Though Figure 14 describes a very capable system, the system elements are not highly integrated. Recent developments in analog and digital signal generation technologies enable a higher degree of integration and solutions which are more cost- and space-efficient.

There are several methods of controlling simulations, depending on test objectives. Figure 14 shows systems with a traditional, distributed architecture. The synchronization of an agile local oscillator (LO) with functions such as pulse modulation, frequency/phase modulation, and amplitude control is a considerable challenge. In an integrated EW test solution such as the UXG, this synchronization is automatic, provided by the test equipment. By simplifying hardware and system complexity, this integrated approach promises to improve both performance and reliability.

Control of hardware-in-the-loop testing

Depending on the integration of simulation elements and the simulation length, scenarios can be played from list memory or streamed over a digital interface such as LAN or low-voltage differential signaling (LVDS). List mode plays PDWs from list memory for shorter scenario lengths with some ability to trigger between lists for an adaptive (closed-loop) simulation in response to the SUT.

For example, there is often a need to switch between one simulated threat mode to another in response to identification and jamming by the SUT. For long scenario lengths with fast control over scenario changes, PDWs can be streamed over the LAN to the signal generation system operating in an agile controller mode. In this case, simulation software generates batches of PDWs according to simulation kinematic granularity and streams them ahead of their desired playtime.

The goals are to stress the SUT with increasing pulse density, depending on the number of simulation channels available and the parameters of the threats to be simulated. As pulse density increases, PDWs can be dropped according to a priority scheme as they increasingly collide in the time domain, and there are insufficient signal generation channels to play them.

Creating AoA

In addition to creating emitters with the desired fidelity and density, it is also important to match the geometry and kinematics of EW scenarios. This is because the AoA of a radar threat to the EW system changes slowly compared to other parameters, such as center frequency and pulse repetition frequency.

EW systems measure AoA and estimate distance using amplitude comparison, differential Doppler, interferometry (phase difference), and time difference of arrival (TDoA). Precise AoA measurements enable precise localization of radar threats. New stand-off jamming systems use active electronically scanned arrays capable of precise beamforming to minimize loss of jamming power due to beam spreading toward a threat. EW receivers with better AoA capability reduce the need for pulse deinterleaving and sorting. Consequently, AoA is an increasingly important test requirement.

Techniques for creating AoA

In the past, AoA was created with a combination of signal sources and analog phase shifters, attenuators, and gain blocks in the cable path to the SUT. Analog elements in the cable path took up space, had limited resolution, and were expensive.

As an alternative, and depending on their architecture, sources can be linked together to create phase-coherent output, allowing for exceptional control over creating phase fronts to the SUT. Similarly, amplitude control at the source can be used to create appropriate amplitude differences at SUT receive channels.

The ability to control AoA to meet modern test requirements depends on the architecture of the source. At a minimum, it should be possible to lock the LOs of multiple sources together, so they all share the same phase. Often, calibration is required to align the phase and timing between sources.

Creating small, accurate, and repeatable differences in phase or frequency between channels is the next challenge. Sources based on a direct digital synthesis (DDS) architecture allow AoA to be controlled digitally in a numerically controlled oscillator. Phase alignment in a DDS source is a matter of sharing reference clocks. Calibrations to provide accuracy and repeatability can be uploaded to a table to be applied in real time.

Overview of source technologies for EW test

The core synthesizer and oscillator technologies used primarily determine the characteristics and tradeoffs of EW signal generation systems. This section summarizes the key technologies currently available:

- Direct analog synthesis (DAS)
- A phase-locked loop or indirect analog synthesis (PLL, frequently fractional-N) – Direct digital synthesis

General source requirements

Signal sources used to test EW systems must be broadband. Traditionally, a frequency range of 0.5 to 18 GHz was required. Frequency requirements have expanded dramatically in recent years, beginning near DC and extending as high as 40 GHz. They allow systems to simulate an early warning, fire control, and missile-seeking radars from a single output channel.

In addition to wide frequency coverage, sources for the EW test must have fast frequency, phase, and amplitude switching speeds to simulate different radars operating in different modes in various frequency bands.

PLLs and fractional-N synthesis

Indirect synthesis

Most general-purpose sources today are PLL-based, where a broadband oscillator such as a voltage-controlled or YIG-tuned oscillator is locked to a stable reference in a phase-locked loop (PLL). The PLL improves signal quality by reducing phase noise and spurious signals in the output. PLL-based sources have been configured with a combination of sum and step loops or a single-loop with a fine fractional division capability. These fractional-N PLLs offer excellent signal quality and fine frequency resolution in a cost-effective single-loop configuration, making them an excellent choice for general-purpose signal sources.

The required control loop filtering in PLLs results in a significant settling or loop response time. This looping limits the ability of the synthesizer to switch frequency quickly. Due to their comparatively high transition time, these sources are limited in their ability to simulate multiple radar threats out of a single channel, even if they have the necessary broadband frequency coverage and resolution. They also lack phase-repeatable switching capability.

Direct analog synthesis

A direct analog synthesizer typically contains several stable frequency references multiplied or divided from the same crystal oscillator reference. These frequency references (and their harmonics) can be switched in and out of the signal path and multiplied, divided, added, and subtracted to provide fine frequency resolution quickly. The frequencies of these references are chosen to reduce the number of multiplication stages required, such that phase noise increases only moderately as the frequency is increased. The division to lower frequencies reduces the phase noise.

Since the switches and arithmetic operators used in the DAS approach operate very quickly and do not need loop filtering, these synthesizers have very high-frequency agility. They are a typical architecture for traditional EW test solutions.

However, DAS technology has several drawbacks. First, numerous stages are required to achieve the desired frequency resolution. Switching parallel and series multiplication, division, and mixing stages require more hardware than PLLs and reduces reliability. Second, circuit noise from each stage is cascaded, and phase noise is multiplied through the stages. Finally, each stage adds components that increase size, weight, and cost.

On the positive side, for EW applications, DAS can limit phase-repeatable frequency switching. All frequencies are usually derived from the same reference, but divider ambiguities generally preclude full phase-coherent switching.

DDS now suitable for EW applications

Based on DAC circuits, the DDS approach is a natural fit for the needs of EW signal simulation. However, until recently, DACs were unavailable with the required combination of fast sample rates and high purity.

Fast sample rates are needed to produce outputs with very wide bandwidth so that a minimum of multiplying stages can be used to create the desired output frequencies. The use of either many multiplying stages or a DAC of insufficient purity would limit the effective spurious-free dynamic range (SFDR) of the EW synthesizer.

In concept, a DDS is one of the simplest types of signal generators. In a frequency-tunable DDS, data from a numerically controlled oscillator is converted to analog form by a DAC and low-pass filtered to remove image frequencies and harmonics. A block diagram of the key elements of a DDS is shown in Figure 15.

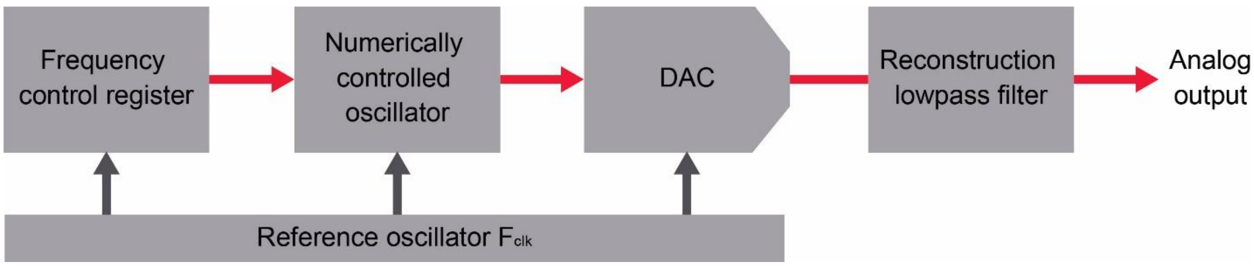


Figure 15. Principal functional blocks of a direct digital synthesizer

Advantages of DDS

The Keysight UXG agile signal generator uses DDS technology made possible by a proprietary DAC to generate multi-emitter simulations. DDS has several advantages over other synthesis technologies for EW applications: Digital control of extremely fine frequency and phase tuning increments within a single clock cycle.

In the UXG agile signal generator, the frequency resolution is one millihertz, and the phase resolution is sub-degree. Fractional-N techniques can provide microhertz resolution, but frequency changes are much slower due to PLL filtering. DAS techniques provide rapid frequency switching but at a cost in frequency resolution.

DAS techniques offer hop speed and frequency/phase repeatability only under limited conditions. Modulation is created in the digital domain, providing numerical precision and repeatability.

Other advantages to using DDS are of interest to the EW engineer. Many DDSs employ a digital modulator for amplitude, frequency, and phase modulation to create digitally modulated signals in the numerically controlled oscillator. Linear frequency modulated (LFM) chirps and Barker codes can also be directly synthesized using the numerically controlled oscillator. Chirp bandwidth depends on the bandwidth of the bandpass filters after each multiplication stage and whether the signal crosses a band.

Advanced Threat Simulation

The DDS architecture provides many advantages for EW threat simulation. As radar threats grow more advanced and sophisticated, threat simulation systems must produce high-fidelity reproductions of these signals. These reproductions include shaped pulses with varying rise and fall times, non-linear chirps, or custom modulation. Implementing these effects with traditional analog building blocks, such as pulse and I/Q modulators, can prove challenging. Fortunately, modern digital I/Q baseband systems can accurately generate these complex waveforms while minimizing distortion and spurious signals.

You cannot create some threat scenarios, such as AoA, with a single-channel source. Those scenarios depend on properly synchronizing the outputs of two or more sources. By precisely controlling the amplitude, phase, and time delay of each source output, you can simulate the direction of a radar wave-front as it reaches the multiple antennas of an EW SUT. Accomplishing this feat with multiple signal generators scales up the cost, often resulting in redundant hardware — adding size, weight, power consumption, and complexity.

The Keysight UXG agile vector adapter works with the UXG agile signal generator. Figure 16 shows the block diagram.

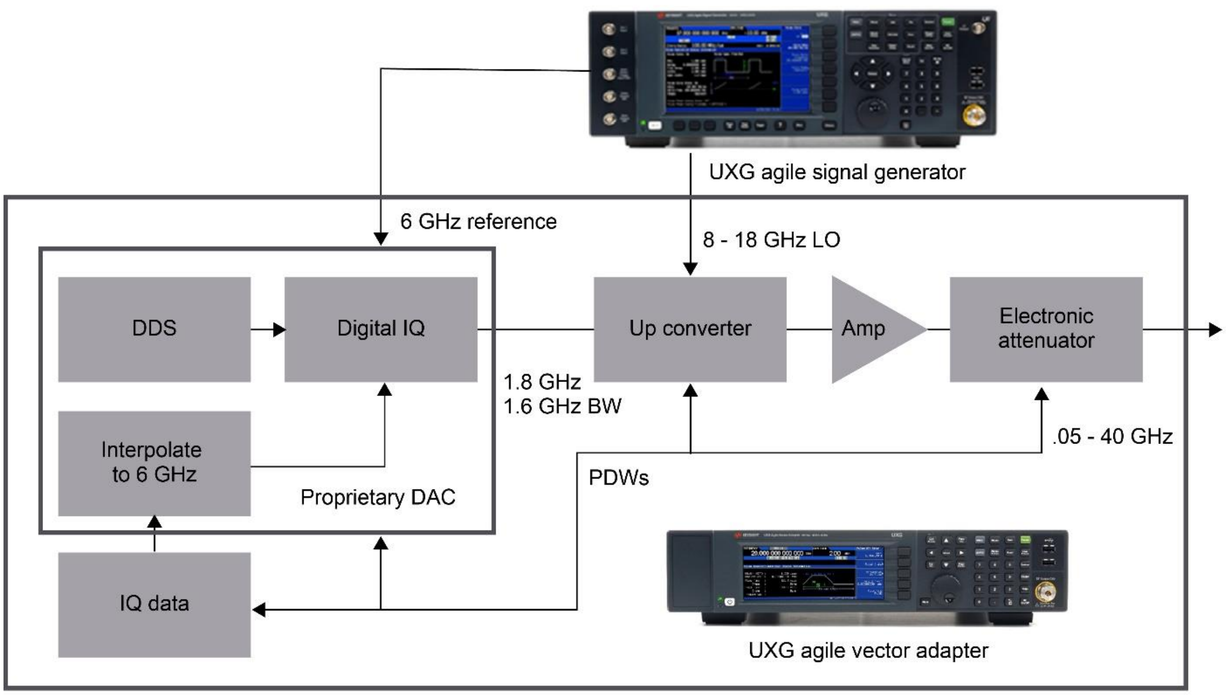


Figure 16. High-level block diagram of the UXG agile vector adapter

The vector adapter utilizes the 6 GHz reference and agile LO signals from the DDS source to avoid duplicating this hardware while adding a digital I/Q baseband system, upconverter, and electronic attenuator. The baseband generator memory stores the complex pulse waveforms represented by I/Q data points. This digital information feeds the DDS engine, where it is converted to an IF signal and upconverted to an RF frequency. An electronic attenuator provides agile amplitude scaling of the signal.

Minimizing Distortion

Traditional analog I/Q baseband systems must be carefully tuned to minimize signal distortion caused by phenomena such as IQ gain imbalance (where the gain in the I and Q channels is slightly different) and IQ skew (where the I and Q paths are not precisely in quadrature). Figure 17 (left image) shows how these imperfections create in-band distortion. These distortion products occur within the signal bandwidth and cannot be filtered out.

A digital baseband architecture mathematically shifts the I and Q channels by 90 degrees and digitally sums them before conversion to an analog IF signal. This technique greatly reduces the amount of in-band distortion. Figure 17 (right image) shows how this technique provides a higher fidelity signal.

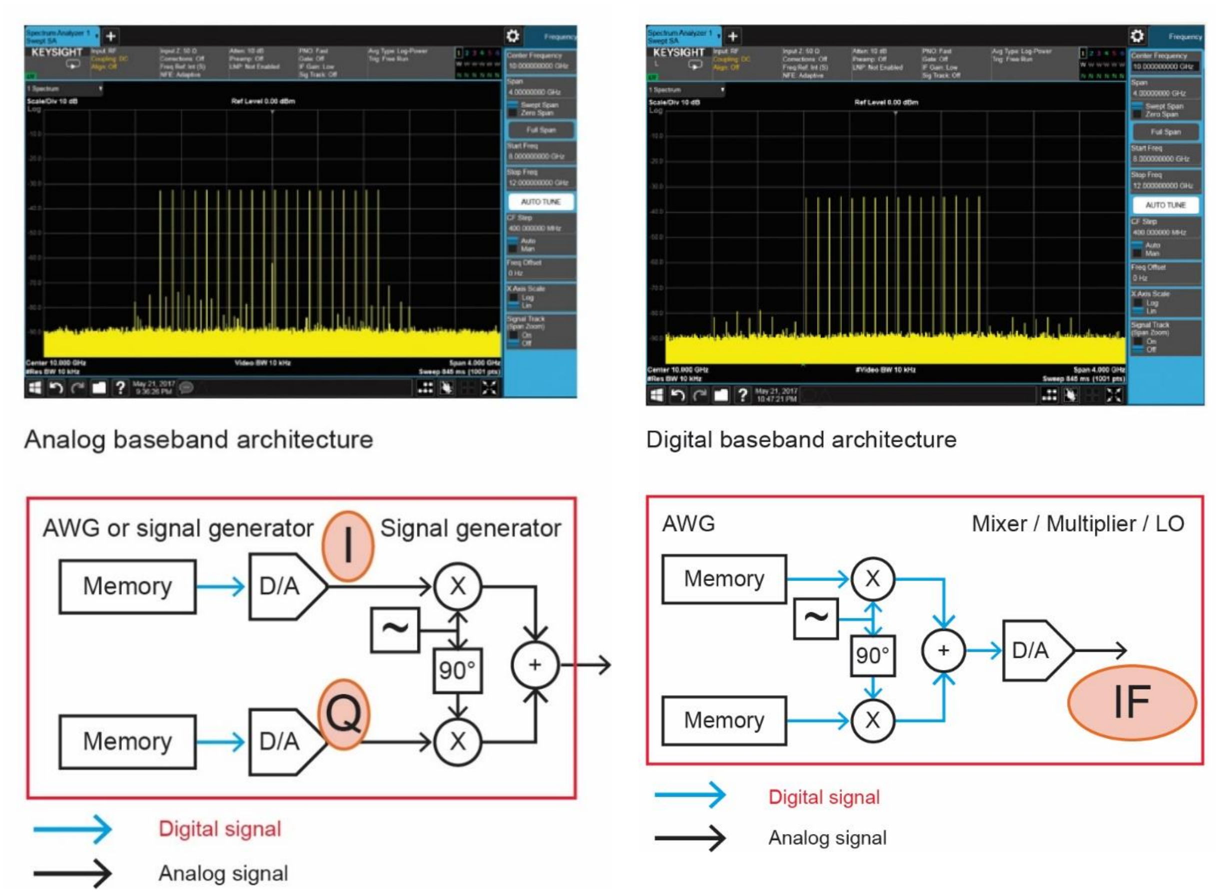


Figure 17. A comparison of analog and digital baseband architectures

Agile amplitude signal control is crucial for realistic threat simulation, where multiple emitters may be at different distances and transmit at different power levels. Mechanical attenuators cannot switch quickly enough to keep up with scenarios that generate millions of pulses per second. To provide agile amplitude control, you can use the baseband generator's digital-to-analog converter (DAC) to scale the signal quickly. Depending on the vertical bits of resolution available in the DAC, this method can provide 40 to 55 dB of agile amplitude range.

This level of performance may impose severe limits on the threat scenario, which could require a higher, agile dynamic range. Moreover, the DAC technique for amplitude control cannot attenuate any spurious signals created further down the signal chain. The EW receiver under test must perform additional signal processing to determine if the detected signal is a genuine threat signal or a spurious one that can be ignored.

Configuring the Threat Simulation System

Depending on the SUT characteristics and the complexity of the desired threat scenario, you may need to configure the threat simulation system to support the differing channel and port counts. A channel refers to the ability to independently tune the threat signal to the desired frequency, while a port refers to the actual output port of the RF signal.

If the scenario requires large numbers of pulses at multiple frequencies with minimal dropped pulses, you might select the 4-channel, 1-port configurations in Figure 18. The outputs of each analog or vector source are combined into a single RF port.

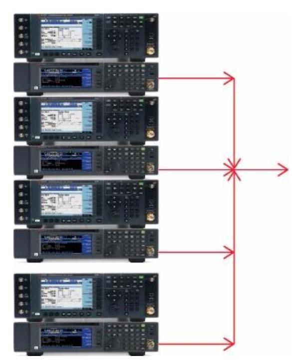
	Analog	Vector
4 channel x 1 port system • 4 pulses at same time • 1 RF connection		

Figure 18. 4-channel, 1-port configurations

If the threat scenario calls for AoA measurements, you need a different configuration. Figure 19 shows two different 1-channel, 4-port test configurations. All four sources are tuned to the same frequency. But the amplitude, phase, and time delay of each RF output are individually controlled to simulate the direction of the threat.

	Analog	Vector
1 channel x 4 port AoA system • 1 pulse at same time • 4 RF connections		

Figure 19. 1-channel, 4-port configurations

More complex scenarios may demand more extensive configurations, such as the 3-channel, 4-port setup in Figure 20. The three channels of this configuration provide high pulse density with pulse-on-pulse capability, and multiple ports for AoA testing.

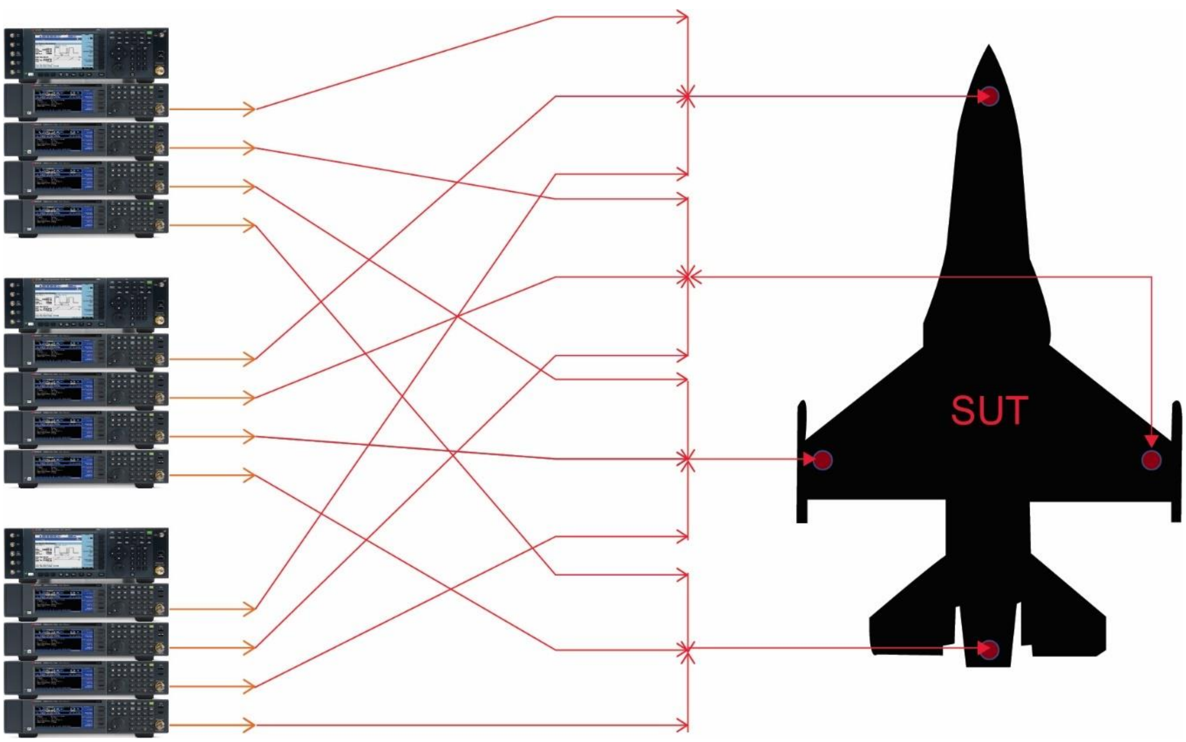


Figure 20. Configuration for 3-channel, 4-port

A variety of traditional technologies have been used to generate the signals needed for effective EW simulation. Each of these technologies has brought a different combination of benefits and challenges. The highest-fidelity solutions have provided realistic simulations of the EW environment, but their complexity and expense have limited their use.

Recent innovations in core hardware, such as DACs and FPGAs, have enabled new solutions with the hardware simplicity and reliability of traditional test equipment. These solutions dramatically improve solution cost and size, bringing high-fidelity EW environment simulation to a much earlier phase in the design process. Using realistic EW environment simulation at the optimization and pre-verification stages of design will improve performance, speed the design process, and reduce overall costs.

References

1. Philip Kazserman, “Frequency of pulse coincidence given in n radars of different pulse widths and PRFs,” IEEE Trans. Aerospace and Electronic Systems, Vol. AES-6, p. 657-662, September 1970.
2. Reproduced by permission from David Adamy, EW 101: A First Course in Electronic Warfare, Norwood, MA: Artech House, Inc., 2001. © 2001 by Artech House, Inc.

Additional Resources

- Keysight UXG X-Series Agile Signal Generators
- Keysight VXG Vector Signal Generators
- PathWave (89600) VSA Radar Pulse Analysis
- PathWave Vector Analysis (89600 VSA) Technical Overview, 5992-4197EN
- PathWave Signal Generation for Pulse Building
- Radar Measurements, 5989-7575EN
- Keysight Care, 5992-3373EN