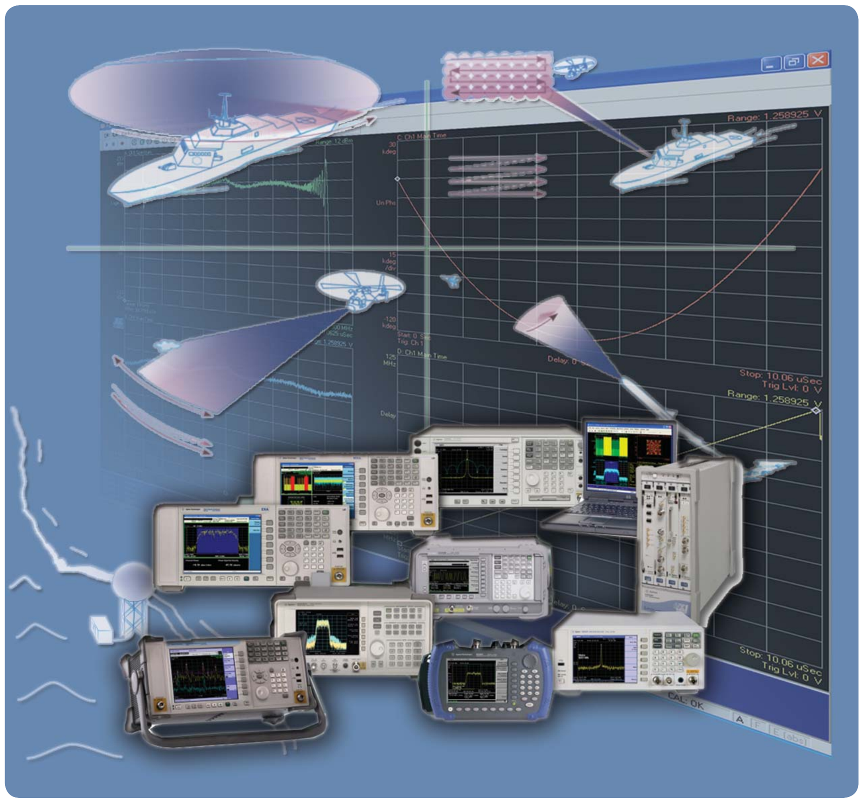
Agilent
Radar, EW & ELINT Testing: Identifying Common Test Challenges

Application Note



Agilent Technologies

Introduction

The U.S. Navy's 1940 radio detection and ranging (RADAR) systems, as they were originally called, have blossomed into a wide array of indispensible equipment for military and civilian use. Today, there are many types of radars designed for numerous applications. Scanning radars, moving target indicators (MTI), Doppler weather radars, guided missile seekers, phased-array early warning systems, ground-penetrating radars, synthetic aperture satellite survey radars, aviation radar altimeters, automotive collision-avoidance radars, aircraft radars and a host of other special-purpose radars define today's growing industry.

With the development of radar systems, often for military purposes, the electronic intelligence (ELINT) that could be gained from radar signals was of great value in coping with the potential threats that are often attached to the radar (ships, planes and missiles). This proved to be the catalyst for the associated technologies called electronic warfare (EW).

Radar systems range from the ubiquitous supermarket door opener, which is a simple MTI detector, to extremely complicated shipboard phased-array fire-control radars. Regardless of complexity, radar, EW and ELINT systems share many common test challenges.

In this application note we will review some of the latest test equipment for radar, EW and ELINT systems. Because this is a complex subject, we begin with a brief review of the fundamental radar and EW/ELINT challenges.

Radar basics — design tradeoffs

Most radars use pulses of RF energy to illuminate their targets. The pulse travels to the target at effectively the speed of light, sometimes expressed as the "radar mile," which is 12.36 μs/mile. With a primary radar system, the RF signal bounces off the target, returning to the radar where the delay between sending the pulse and receiving the return echo can be measured. Secondary radars are similar, but use a transponder located on the target to re-transmit the received pulse, delivering more energy in the return echo and often some data.

Radar pulses are usually bursts of RF energy in the form of a pulse-modulated RF carrier. Important radar pulse characteristics are pulse width (PW), pulse repetition frequency (PRF) or pulse repetition interval (PRI), mean power pulse-on and average signal power.

When designing a radar system, pulse width is a key parameter in the radar's performance capabilities.

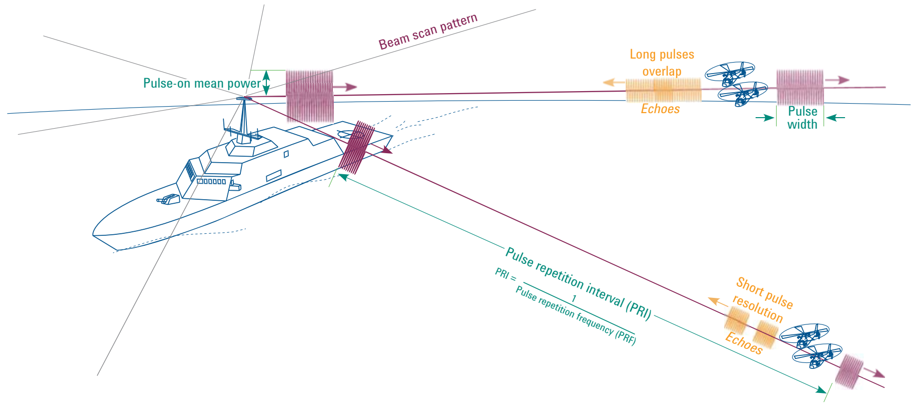


Figure 1. Radar pulse terminology and tradeoffs

Primary radars suffer significant signal losses from the transmitted pulse to the received echo. The transmitted signal must bounce off and travel back from the target to the receiver without amplification. One way to overcome these large signal losses is to transmit longer pulses and integrate the larger total energy in the received echo. A longer pulse width thus provides longer operating range for a given antenna and transmit power amplifier.

Radar "resolution" is also an important characteristic related to pulse width. The ability to resolve small objects allows a radar to provide a more detailed picture of the target. A radar that can resolve details down to 1 meter will provide much more information about approaching targets. A resolution of 100 meters might render one large target indistinguishable from several smaller ones in close formation.

If a radar's pulse width is long, echoes from adjacent targets can bounce back together, overlapping in time. To the radar, this appears as one large target instead of adjacent smaller targets. Thus, to get the best radar resolution, a narrower pulse width is desirable.

One can see that optimal range and resolution involves conflicting criteria. Best range implies a long pulse whereas best resolution implies a short pulse.

To solve the range-versus-resolution optimization problem, many radar systems use pulse compression or modulation.

The linear frequency chirp is in concept, both a simple modulation to create and to decompress. Frequency modulating (FM) the radar pulse with a linear voltage ramp creates a frequency-chirped pulse. The chirped pulse is then transmitted, as an uncompressed pulse would normally be.

The radar receiver uses a special filter with a significant linear group delay opposite that of the chirped pulse. The filter's group delay slows the lower-frequency portion of the chirp and allows the higher-frequency part of the chirp to emerge from the filter earlier. This has the effect of taking a long pulse, easily integrated for greater total power, and compressing it to a short pulse easily identified amongst other pulses.

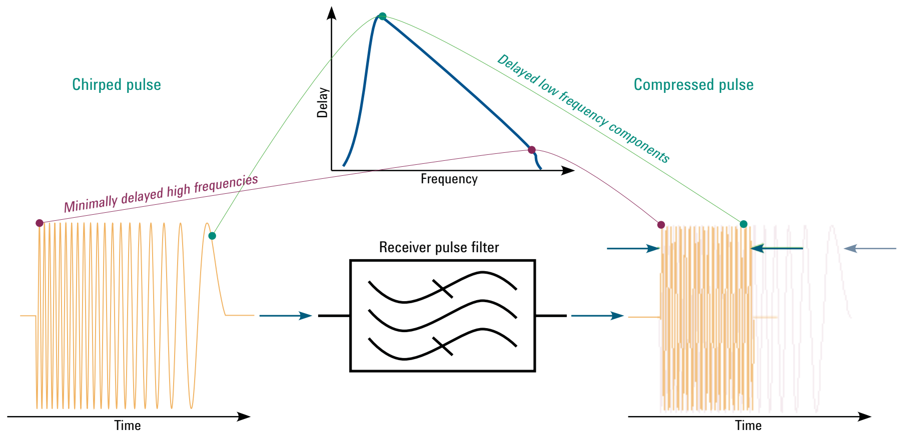


Figure 2. Frequency chirped pulse compression

Pulse compression or modulation offers other advantages in unambiguous range. To see these advantages, let us consider the pulse repetition frequency.

The PRF is dependent on the range capability of the radar. Sending new pulses out before previously sent pulses can echo back can cause an ambiguity in the echo response. Generally it is easiest to send a pulse out and wait until all possible echo responses have been received before sending the next pulse. Providing an unambiguous range response determines the PRI or PRF between successive pulses.

There are many cases, however, in which a slower PRF degrades overall radar performance. For example, it might be preferable to have a higher PRF for a faster radar screen update rate if the radar is tracking a fast moving aircraft. In this case, the PRF might allow an ambiguous return in favor of a faster update rate.

One approach to eliminating the clutter of echoing returns that are not from a range of interest is to use time or range gating. This approach blanks on or off the radar's receiver, ignoring echoes from objects either too close or beyond the range of interest. An example might be a time gate that ignores echoes from the bow of the ship the radar is mounted on. Similarly, a missile might use time gating to ignore echo returns beyond the missile's maximum range.

As mentioned earlier, pulse compression can be used to eliminate ambiguity between successive pulses. Adding digital modulation to each pulse allows the adjacent pulses to be uniquely encoded. Using digital modulation techniques, such as bi-phase keying, encodes pulses so the round trip delay of each pulse is easily measured unambiguously using each pulse's unique coding as a separating tool.

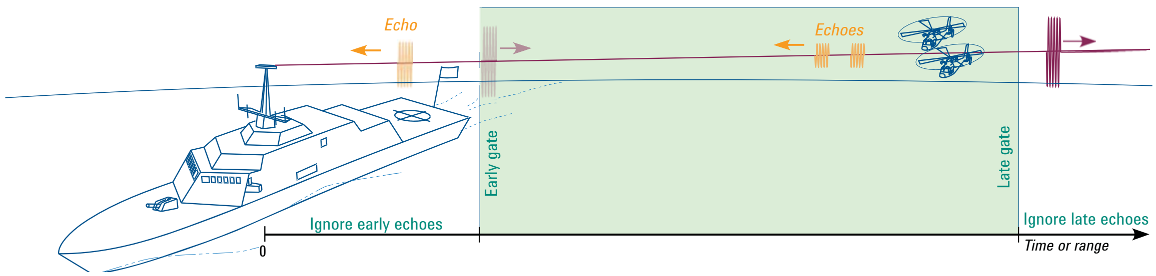


Figure 3. Time gating or range gating

Another important feature of many radars is the ability to measure Doppler shift from moving targets. Measuring the change in frequency of the RF carrier or phase shift with time allows some radars to accurately determine the target's speed. MTIs use Doppler shift in the return echo to sense movement.

ELINT/EW basics — What is out there?

The various design criteria that influence the chosen radar pulse pattern also convey a great deal of information about the nature of the platform attached to the radar. A slow PRF with a long pulse might indicate a weather radar scanning across hundreds of miles, where a fast PRF and a short pulse width might indicate a missile's terminal homing radar scanning across a mile or two. The ELINT gained from these signals conveys vastly different information.

Similarly, the scan pattern of the radar can also convey valuable information about threats in the local environment. For example, observing the signal amplitude as a function of time can reveal the type of antenna the radar is scanning with and the pattern the antenna is scanning out. This type of intelligence is helpful for understanding what the radar is illuminating and how it is being used.

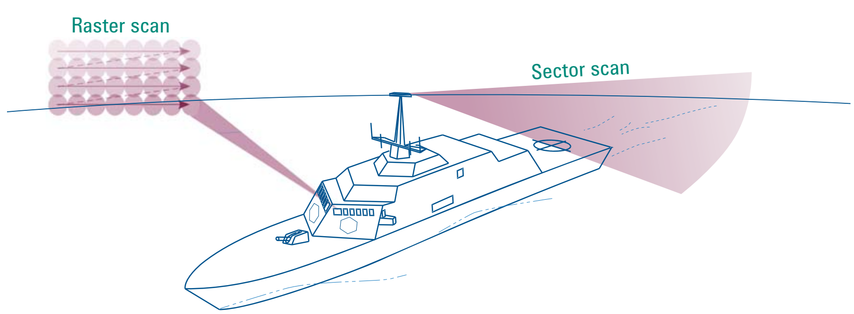


Figure 4. Antenna scan patterns

Beyond simply gathering ELINT information about the radar and its attached platform, knowledge about the radar can enhance and guide electronic warfare techniques. For example, echo patterns can be synthesized and broadcasted to an early warning radar receiver to display assets that are physically not there. Missiles can track false radar returns that alter their range gating to ignore their intended targets. Doppler information can also be used to confuse targeting equipment.

Modern radar & EW test challenges

The above review of some of the design issues with radar, ELINT and EW equipment highlights the level of circuit complexity required. Testing these modern radar systems places unique demands on test and measurement equipment. Let us briefly consider some common challenges encountered in testing.

Wide bandwidths are essential for many radar signals. Chirped or modulated pulses can require gigahertz of bandwidth, demanding broadband test equipment resources.

Very low phase noise is another common requirement of radar test equipment. Radars that use Doppler shift information often measure the rate of phase shift over time, as radar pulses may not be long enough to integrate cycles of frequency difference. When making these precision phase-change measurements, phase noise must be kept very low, placing stringent requirements on the phase-noise performance of the test instrumentation.

Similarly, dynamic range requirements can challenge radar test systems. Generally this stems from the large path losses encountered from the transmitter through the return echo.

As we have seen thus far, the many advantages of using compressed pulses for better resolution and unambiguous range frequently give rise to the need for complex test waveform synthesis. This can be further compounded by the need for added Doppler shifts for radars that determine velocity.

Another challenge facing radar system designers is the ubiquitous use of software-defined radar systems. Many modern types of radar not only require test signals and measurements in the traditional analog RF fashion, but also in digital formats. This multi-format testing can present a real problem trying to get good agreement between digital signal measurements and analog measurements.

Full-scale system test is often a major issue for radar, ELINT and EW equipment. The primary issue is usually the cost of the test assets. For example, simulating Doppler shifts, clutter and other signal elements to test a shipboard fire control radar may require a ship and multiple test aircraft. Such test platforms can quickly run into a cost of many tens of thousands of dollars per hour to accurately test targeting performance.

Finally, many radars use phased-array antenna systems. These antenna systems use wavefront time-of-arrival among many antenna ports to steer the antenna beam. This calls for test signals and measurements that provide multiple channels of phase-coherent and phase-adjustable sources or analyzers. The so-called multi-channel array test system poses some very real challenges to the radar test engineer.

Having examined some of the basics of radar systems and the test challenges they pose, next we will look at the unique features of Agilent's test equipment that make some of the radar engineer's difficult test challenges much easier to solve. We begin with the generation of radar test signals.

Generating Test Signals

Many situations in the design and manufacture of radar systems require microwave signal generators. Test sources are typically used for applications such as stable local oscillator (STALO) substitution, coherent oscillator (COHO) testing, as well as synthesis of radar pulses and echos.

One key problem associated with radar test is generating return echoes that accurately portray the types of signals received by the radar. Consider for a moment that when a radar pulse is sent out, its return echo arrival is timed. In the laboratory or manufacturing environment, it is difficult to simulate an echo reflection from a target 50 miles (80 km) away with a microwave delay structure. Instead, modern signal generators and arbitrary waveform generators use digital techniques to synthesize echoes with proper delay and path distortion to accurately portray such distant targets. Similarly, ELINT/EW equipment requires test signal sources capable of generating signals that mimic real world signals and threats.

Agilent arbitrary waveform generators & sources

The microwave arbitrary waveform generator (AWG) has revolutionized the testing of these systems, providing a simple way to simulate a virtually limitless variety of radar signals. Radar emitters and targets scattered over a synthetic test range simulating hundreds of cubic miles of radar surveillance space are easily synthesized with an AWG.

The true beauty of the AWG is in its ability to synthesize virtually any waveform programmed into its memory. However, there are a variety of limitations to be aware of with AWGs.

Figure 5. Agilent arbitrary waveform instruments

Historically, bandwidth has been a crucial limitation for AWGs; however, the latest generators have largely resolved this problem for most applications. Sample rates of 1.25 GSa/s and 4 GSa/s can provide alias-free bandwidths of 500 MHz and nearly 2 GHz. Using combining and converting technology, even greater alias-free bandwidths can readily be achieved. Third-party systems that use Agilent AWGs routinely generate 6 GHz of RF bandwidth, with 70 dB of dynamic range.

Perhaps the more important consideration when selecting an arbitrary waveform generator has to do with the spurious free dynamic range (SFDR) of the source. Does the source's digital to analog converter (DAC) have enough bits of resolution to adequately represent the desired signals? Also, is the spurious free dynamic range maintained in the frequency conversion to microwave?

Theoretically, for each bit of resolution, 6.02 dB of SFDR are possible. In practice for DACs, we often speak in terms of effective number of bits (ENOB) or the equivalent number of bits of a DAC, taking into account linearity issues, which reduce the 6.02 dB/bit theoretical capability.

Broadband DACs also suffer from passband tilt, which further lessens the dynamic range at the higher end of the band. Because of the sampling function (sin x)/x rolloff, passbands from the AWG roll off with increasing frequency; however, because this tilt is inherent in the sampling function, it is not considered when specifying the SFDR. Thus, if an SFDR of 65 dB is specified, it is generally for the lowest frequency in the band. At the upper frequencies of the band, the dynamic range will typically be reduced by 5 to 7 dB from the sampling function and Nyquist filter rolloff.

In addition to the number of bits and inherent sampling function loss of SFDR, upconversion to microwave frequencies poses another set of problems for the creation of useful signals. Radar, EW and ELINT synthesized receivers are typically very sensitive with more than 75 dB of SFDR. The large path losses encountered with radar signals – typically twice that of most communications signals from double the round-trip distances – require a powerful radar transmitter with a very sensitive receiver. This is why many radar systems have demanding dynamic range requirements. Most radar systems typically operate at S-Band or X-Band, requiring a frequency upconversion from the baseband arbitrary waveform generator’s DAC.

This upconversion can either be performed internally by the signal source or externally with a separate device. Simple in concept, it would seem easy to upconvert the signal to the band of interest using a mixer and a couple of filters with a fixed local oscillator (LO). In practice, however, LO harmonics and spurs often combine with the desired signal to create in-band spurious signals that can severely limit the SFDR.

Because the best of today’s AWGs can exceed 75 dB of SFDR, most test professionals realize that it is generally not economical to add external upconverters for signal bandwidths less than 2 GHz, instead opting to purchase a microwave source with the arbitrary waveform generator and upconversion hardware built in. This is particularly true if phase noise is important to the measurement application.

Many radars measure pulse-to-pulse phase shifts as a means to derive the Doppler shift or target velocity. To combat the addition of significant phase noise in the upconversion process, low-phase-noise sources are essential. This compounds the difficulty of making a suitable external upconverter.

Agilent offers a full line of signal sources and AWGs with industry-leading SFDR. Of particular interest to the radar and EW professional is the Agilent E8267D microwave vector signal generator used in conjunction with the Agilent N8241A arbitrary waveform generator. These two high performance instruments can deliver 2 GHz of signal bandwidth up to a maximum frequency of 44 GHz with industry-leading SFDR and phase noise.

The Agilent N81180A is also of interest to the radar and EW professional, offering a variable sample rate up to 4.2 GSa/s or 2 GHz of RF bandwidth.

Another important consideration when selecting a source with arbitrary-waveform capabilities is the memory configuration. Arbitrary waveform generators play digital data from memory to construct analog waveforms. The organization of this memory along with options for sequencing and playback can either enhance or limit the utility of the generator.

The simplest approach to organizing the waveform memory is to use a single large block of fast solid-state memory, and play the waveform back out of memory. This works well for a single pulse or very short RF events, but at the rapid data rates required to support 1.25 GSa/s using 15-bit DACs, the test of interest must be very short. Some equipment vendors have extended this approach to work with a large fast redundant array of inexpensive disk drives (RAID) to enable longer playback times.

The single large block of memory playback approach, though simple in concept, is very limited in application because most RF signals are repetitive in nature. Even with terabytes of memory, sequential playback times can be limited to a few seconds of signal. Typically what is needed is a more efficient memory-access capability for repetitive signals such as radar pulses.

To more appropriately fit the repetitive signal, the fast playback memory to the DAC can be organized to play signal segments repetitively. These segments can either be played in loops or in an infinite sequence. This allows repetitive continuous signals to be synthesized far beyond the few seconds of a deep memory RAID array. Even complex segments can be created using a scenario table. Some Agilent sources also offer dynamic sequencing, allowing real-time modification of the waveform segment played back by the source.

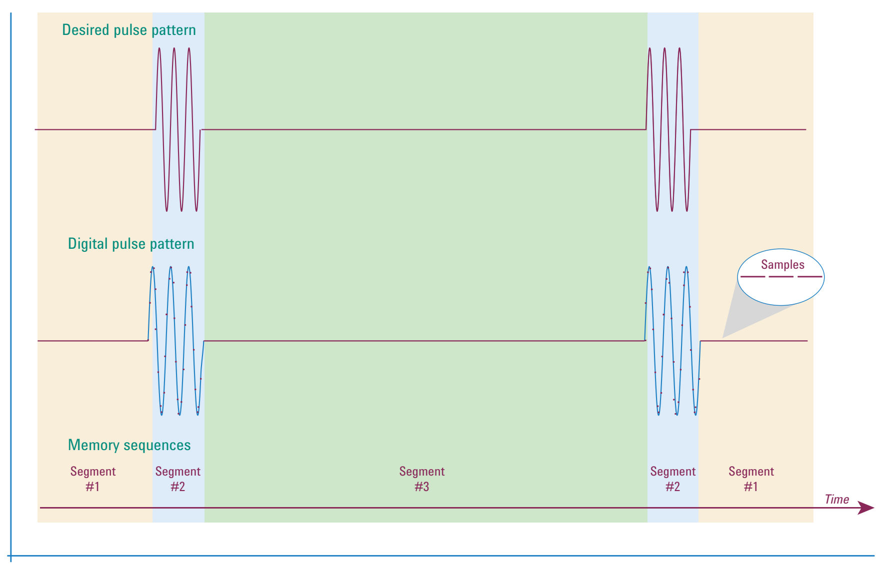


Figure 6. Waveform segmenting, sequencing and scenarios

Once the radar professional selects the appropriate signal source with adequate bandwidth, SFDR and powerful waveform sequencing, the next challenge is to digitally create the desired waveform to download to the arbitrary waveform generator or microwave source.

Signal Studio for Pulse Building Features

A wide array of software defined or imported pulse shapes and antenna patterns are supported by Signal Studio for Pulse Building II.

Pulse Characteristics:

- PRI or PRF
- Number of Repetitions
- Frequency
- Phase
- Power Offsets on a Pulse-by-Pulse

Intra-Pulse Modulation:

- Linear FM Chirps
- Non-Linear FM Chirps
- FM Steps
- AM Steps
- BPSK
- QPSK
- Barker Codes

Antenna Scanning Patterns:

- None
- Custom
- Circular
- Conical
- Bidirectional Sector
- Unidirectional Sector
- Bidirectional Raster
- Unidirectional Raster

Antenna Radiation Patterns:

- Blackman
- Hamming
- Hanning
- Rectangular
- 3 Term
- Cosine1
- Cosine2
- Cosine3
- Cosine4
- Cosine5
- Programmable

Easy pulse building for Agilent sources

As mentioned in the introduction, radar pulses come in a wide range of pulse widths, PRF and modulations based on the particular applications of the radar. Further complicating the synthesis of the test radar pulse are the desired system diagnostics. Is a Doppler shift or pulse-to-pulse phase shift needed to test velocity measurement capability? Is the goal to test an ELINT system that may be identifying the pulse source based on the antenna-scanning pattern? All these aspects greatly complicate the variety of pulse patterns needed from the waveform digital synthesis software.

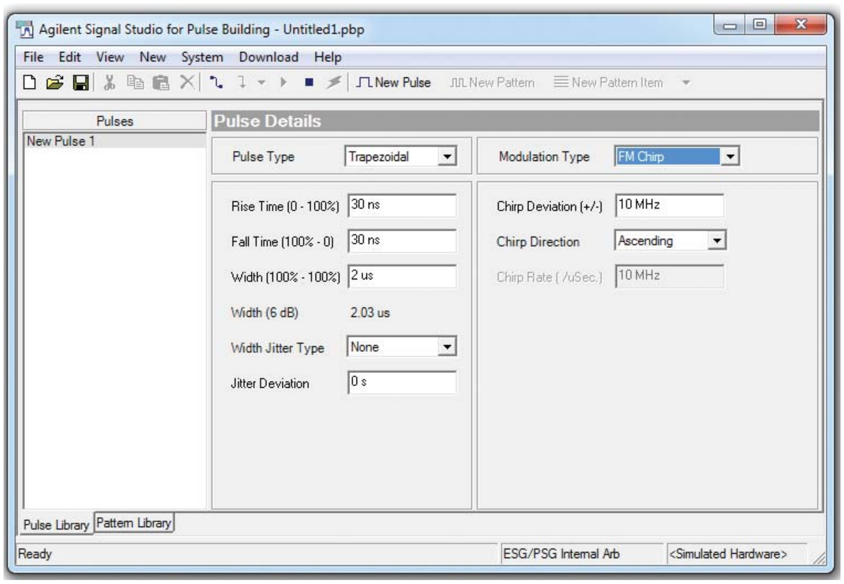


Figure 7. Pulse definitions and patterns screen capture

Agilent has recognized these challenges and created Signal Studio for Pulse Building. Signal Studio for Pulse Building provides an easy way to enter the basic pulse characteristics for simple on-off pulses or complex custom compressed pulses. Each pulse definition stored in the library can be aggregated into pulse patterns to synthesize complex sets of radar emissions.

Once the pulse parameters have been entered, the next step is to simply download the waveform to the AWG or signal generator. The test stimulus will then be ready to play.

Antenna pattern simulation

Signal Studio for Pulse Building features a variety of antenna pattern simulations that can be applied to waveforms. This feature is particularly useful for ELINT and EW applications in which the system to be tested needs to be immersed in a signal-rich environment that mimics real-world threats that may not be available. Many of these ELINT and EW systems use antenna pattern information to identify the particular threat being received.

Radar antenna patterns are somewhat unique because they usually involve a scanning or moving antenna beam dictated by the nature of the radar's mission. For example, a ship might have a rotating scan pattern to view objects on the ocean surface in all directions. A fighter jet likely employs a forward sector scan for its weather radar. A guided missile cruiser may use a phased-array antenna for its targeting radar, and the missile launched from the ship could well use a conical-scanning terminal radar.

Testing ELINT and EW systems that respond to these types of threats requires the ability to produce the appropriate pulse pattern that mimics the scanning radars.

Agilent's Signal Studio for Pulse Building supports a variety of antenna scan patterns, including circular patterns commonly found on ships, sector patterns found on aircraft, conical patterns often used on missiles, and raster scans typical of targeting phased arrays.

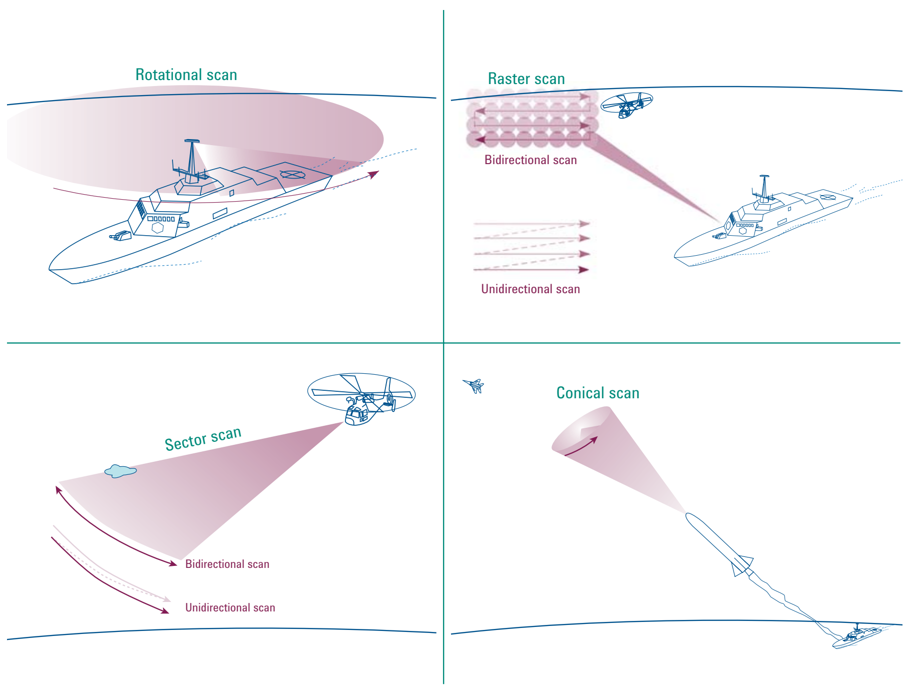


Figure 8. Antenna scanning patterns

To accurately simulate a scanning antenna, it is also necessary to take into account the effects of the antenna side lobes. Because all directional radar beam antennas are of a finite size, they all exhibit some form of off-axis side lobe. Thus, as a radar scans, the main lobe of the antenna pattern is preceded by side lobes, then the main beam and finally more side lobes.

Combining the amplitude modulation caused by the scanning antenna and its side lobes with the pulse envelope modulation and its internal pulse compression modulation can be a complex affair.

Agilent has made this process easy with Signal Studio for Pulse Building by allowing the user to also define antenna side lobes, pointing angles, target location, scan rates, beam widths, and roll off rates.

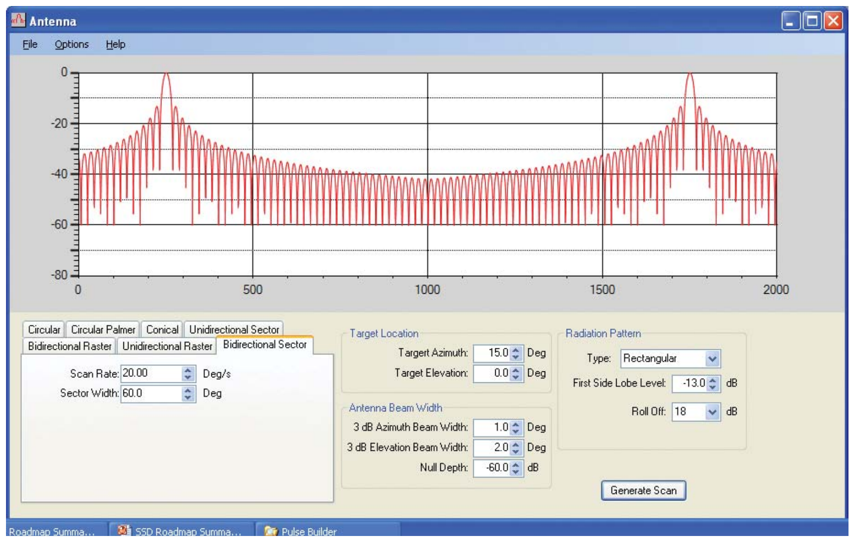


Figure 9. Antenna scanning simulation in signal studio for pulse building

Signal Studio for Pulse Building also allows the user to define the antenna radiation patterns using popular spatial transform windows. Blackman, Hamming, Hanning, Rectangular, 3 Term, Cosine and even programmable windows are available for describing the spatial distribution of energy.

Pulse pattern libraries

The need to generate feature-rich pulse patterns to simulate complex EW environments continues to grow with sophisticated equipment designed to respond to multiple threats automatically. Many organizations have cataloged emissions from a variety of radar sources to enable EW and targeting equipment to be pre-programmed to respond to each threat appropriately.

Signal Studio for Pulse Building is designed to interface with popular databases, including Microsoft® Excel spreadsheets, to enable easy import of pulse characteristics. This handy import feature makes it easy to generate realistic EW mission scenarios to test radars and countermeasure equipment.

Baseband pre-distortion

In terms of dynamic range, playing back recordings of mission scenarios is much like playing an analog music recording. If the recording's dynamic range is poor, the utility of the recording as a test signal may be of little value in determining the response of radar or EW equipment.

Agilent AWGs and signal sources have the best-available SFDR, a key selection criterion in many applications. To further expand the utility of these instruments, Agilent also offers the ability to enhance their performance with digital baseband radar pulse pre-distortion.

Nonlinear effects in the DAC and subsequent components can distort the pulse pattern by causing intermodulation of the frequency components that make up the pulse. The intermodulation components effectively reduce the test signal's dynamic range.

Using digital pre-distortion of the Pulse Building synthesized waveforms allows these intermodulation products to be suppressed for unsurpassed dynamic range or amplified for margin testing.

With the addition of an external Agilent signal analyzer like the N9030A PXA, the synthesized test pulse pattern is analyzed and pre-distortion components are added in the source to compensate for test system nonlinearities. This sophisticated test system is easy to use, automatically determining and applying corrections to the measurement, which minimizes intermodulation distortion (IMD) products.

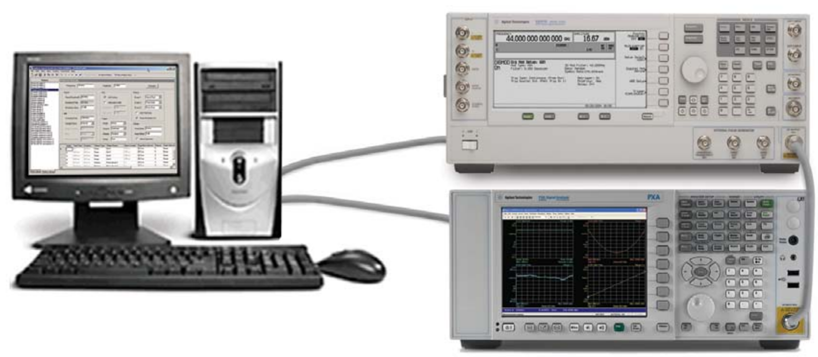


Figure 10. Digital pre-distortion with the Agilent PSG

Now that we have seen how Agilent sources with Pulse Building can create detailed radar pulse patterns, how can this equipment provide the radar or EW engineer with a distinctive competitive edge when building mission-critical equipment? Let's examine some of the advantages with a synthetic test range example.

Synthetic Range Testing Example

As mentioned earlier, testing radars can be challenging. Historically, the radar engineer would rely on a field test range, usually a large area where several ships or airplanes could be steered about to evaluate if the radar would properly display their position and velocity. Though field testing often provides a realistic environment, it is generally an inferior option for the development engineer.

The challenges of working in the field are the primary reason that many radar test engineers choose to create a synthetic test range. The synthetic test range is a collection of test equipment capable of simulating the types of radar return echoes needed to test a radar's performance.

Though field testing can be helpful in simulating environmental conditions such as coastlines, mountains and clouds, it is often impractical to simulate realistic military mission scenarios. For example, it can be exorbitantly expensive to organize a full-scale attack that includes dozens of aircraft and ships approaching a coastal early warning radar station. In a similar vein, field testing may entail significant safety issues (e.g., potential collisions) that are not a factor in laboratory testing.

Finally, with many large-scale field tests it is often impossible to explore multiple scenarios. The cost of positioning radars and targets over hundreds of miles of range multiple times prevents fully exploring the capabilities of a radar, EW or ELINT receiver. Similarly, when testing spacecraft radar systems, field testing is cost prohibitive.

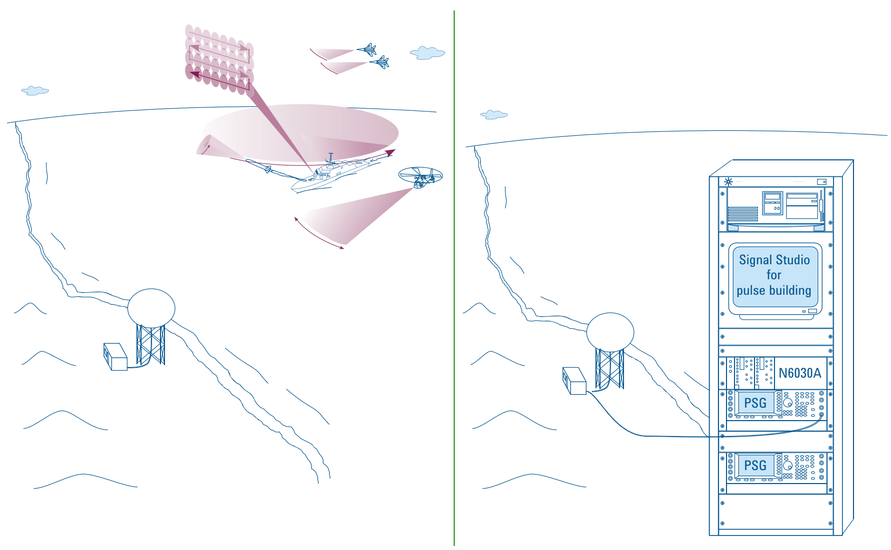


Figure 11. Field testing versus the synthetic radar test range

To overcome these issues, Agilent signal generators and arbitrary waveform generators along with Signal Studio for Pulse Building can create a synthetic test range in the laboratory environment, which is often preferred by the radar and EW engineer.

Simulation of scanning antennas

To illustrate the application of the signal generator to test an EW system, consider the problem of testing a shipboard early warning system. In this case, the EW system receives the radar pulses hitting the ship and analyzes them to determine the nature of their source and bearing angle to the source. Examining the pulse patterns as well as their varying amplitude caused by the antenna scanning pattern provides critical information to an EW countermeasure system.

The key to a successful test strategy is to provide a realistic set of radar pulse patterns and see if the EW countermeasure system takes the appropriate action such as jamming, range gate pull-off, chaff dispensing, and the like. In this example, we wish to see how the EW system responds to different radar signals such as those from a pleasure boat's radar or a surface-skimming missile.

To implement this test, we need only Agilent's Signal Studio for Pulse Building II and an Agilent PSG. Using the appropriate radar pulse definitions and antenna patterns, the different threats can be played out of the Agilent PSG to the EW system to see if it takes the appropriate action. In the case of the pleasure boat, nothing should happen, while in the case of the missile, the EW system should initiate the appropriate countermeasures.

Synthetic test ranges using Agilent test instruments not only provide realistic testing of shipboard equipment at a fraction of the cost of "live-fire" exercises, but they also provide excellent training simulators. For example, consider a ship that is in port for maintenance or restocking. Using a synthetic test range built around Agilent sources, the ships radar and EW receivers can be used to train ship personnel to deal with a variety of likely mission scenarios. This can be done without alerting unfriendly forces, which is a notable downside of at-sea exercises.

Coherent multi-channel receiver test

Agilent sources and Signal Studio for Pulse Building can also be configured to deal with phased-array radars. Modern phased-array radars have many receiver inputs and rely on the phase of arrival of the traveling electromagnetic waves produced by echoes. This can complicate testing because multiple sources are needed to provide a receive signal that mimics radar echoes arriving from distant points. To accurately simulate this arriving wavefront, many signal sources may be needed.

Agilent has addressed this issue with signal sources such as the Agilent PSG and MXG, which can be coherently phase-locked together with the ability to adjust the static phase relationship between each source. This allows Agilent sources to mimic pulse wavefront arrival for multi-channel phased-array systems. The reader may wish to review the application note *Agilent Coherent Multi-Channel Test,* (literature number 5990-5442EN) for more details on how this is accomplished.

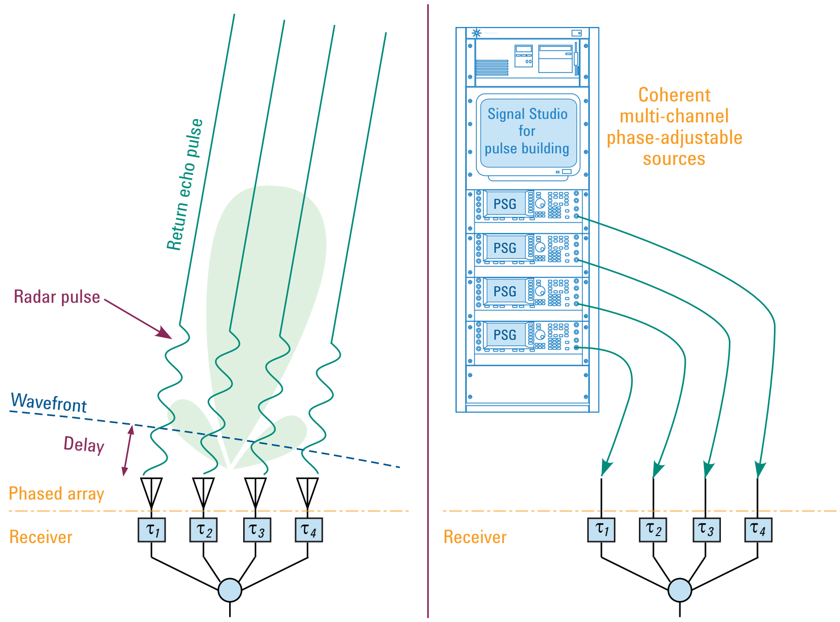


Figure 12. Creating a synthetic test range for phased-array radars

An alternative environment for system simulation and signal creation

Signal processing algorithms play an important role in advanced radar systems, especially high-performance multi-mode systems. Algorithm creation is a complex process that becomes more efficient when developers have access to a sufficient set of models for the various radar elements and functions: signal generation, transmission, antenna, transmit/receive switching, clutter, noise, jamming, receiving, signal processing and measurements.

The Agilent W1905 library works within the Agilent SystemVue system-level design environment. SystemVue is an open modeling environment focused on physical-layer architectures at baseband and RF. It replaces general-purpose digital, analog and math environments, and it connects to a variety of FPGA and embedded-hardware design flows.

The W1905 radar model library provides more than 40 highly parameterized simulation blocks (Figure 13) and 16 higher-level reference designs. With these tools, developers can model different types of radar systems, create radar signal processing algorithms, evaluate system performance and provide proof-of-concept designs.

Together, SystemVue and the W1905 radar model library create a system-level platform for design and verification that enables effective creation of signals and signal-processing algorithms. The platform provides a user-friendly environment for modeling and debugging that supports a variety of languages (e.g., C++ and math language).

Name	Description
RADAR_AmbgtResolution	RADAR range and velocity ambiguity resolution
RADAR_ARRAY_FILTER	Array Optimum Filter
RADAR_BarkerCode	Barker Coded Waveform Generator
RADAR_CFAR	Constant False Alarm Rate
RADAR_CICDecimate	RADAR CIC Decimation
RADAR_CICInterp	RADAR CIC Interpolation
RADAR_Clutter	RADAR clutter simulation
RADAR_Clutter_2D	Radar clutter simulation
RADAR_Clutter_H	Radar clutter simulation
RADAR_DBF_Clutter_2D	Digital Array Radar clutter ring simulation
RADAR_DBF_Target_2D	Radar target 2D simulation for digital beamforming, including RCS, Doppler
RADAR_DDC	RADAR Digital Down Converter
RADAR_Detector	RADAR Detector
RADAR_DUC	RADAR Digital Up Converter
RADAR_FrankCode	Frank Coded Waveform Generator
RADAR_LFM	Linear Frequency Modulation Waveform Generator
RADAR_MatchedSrc	generate the matched source signal for pulse compression
RADAR_MTD	Moving Target Detection
RADAR_MTI	Moving Target Indication
RADAR_MultiCH_Rx	Quadrature amplitude demodulator with internal oscillator
RADAR_MultiCH_Tx	RADAR ideal multichannel transmitter
RADAR_NLFM	Non-Linear Frequency Modulation Waveform Generator
RADAR_PC	Pulse Compression
RADAR_PD	Pulse Doppler
RADAR_Pd_Measurement	Detection Probability Estimation
RADAR_Pf_Measurement	False Alarm Rate Estimation
RADAR_PhaseShift	RF phase shifter continuously interpolated between time steps
RADAR_QuadSample	RADAR quadrature sampling
RADAR_RCS	Radar target RCS
RADAR_Rx	RADAR Receiver Front End
RADAR_Rx_4x4	RADAR Receiver Front End for 4x4 MIMO
RADAR_Rx_DBS_2D	2D Rectangular Array Digital Beam Synthesis
RADAR_STAP	2D Rectangular Array Space-Time Adaptive Processing
RADAR_SummerBusRF	RF signal summer
RADAR_Target	Radar target simulation, including RCS, Doppler effect, Delay and Attenuat
RADAR_Tx	RADAR Transmitter Front End
RADAR_Tx_4x4	RADAR Transmitter Front End for 4x4 MIMO
RADAR_Tx_DBS_2D	2D Rectangular Array Tx Digital Beam Synthesis
RADAR_Tx_DBS_Measur…	RF transmitter antenna pattern measurement
RADAR_Tx_Synthesis	RF transmitter antenna array synthesis

Figure 13. Block list for the W1905 radar model library

The library is also ideal for those who need to generate precise signals for verification of algorithms and hardware, or study the performance of radar systems under various conditions. For example, a key aspect of receiver testing is assessing its performance when faced with background clutter, multipath, ambiguous echoes, jamming interference and channel impairments. SystemVue provides modeling capabilities that support these applications (Figure 14).

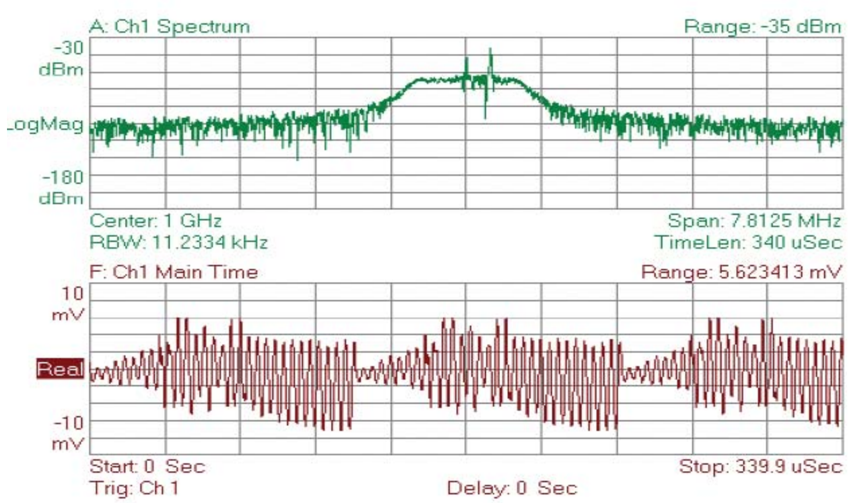


Figure 14. SystemVue and the W1905 were used to create these return signals with clutter and jamming

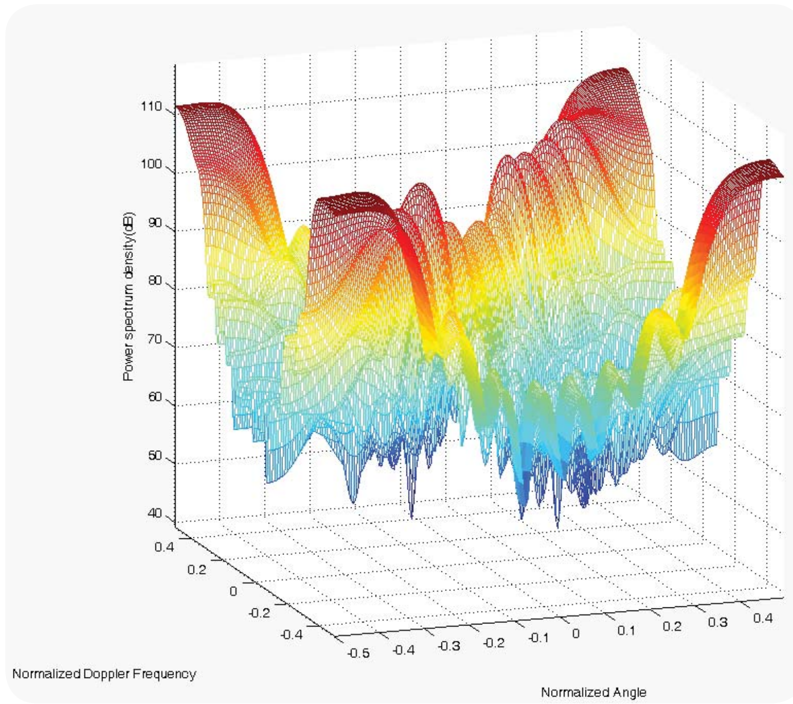


Figure 15. SystemVue was used to analyze pulsed Doppler target returns in this scenario with clutter models. Tight MATLAB integration within SystemVue allows this result to be visualized easily in 3D.

To illustrate the creation of a radar test signal, please refer to Figure 16. In this configuration, an interface model (Sink) in SystemVue connects to a vector signal generator such as an Agilent MXG, PSG or ESG. Any radar waveforms SystemVue generates in simulation can be automatically downloaded at runtime into the signal generator, which can produce the same signals for use as RF or IF test signals during hardware testing (Figure 16). Waveforms captured by the signal analyzer can also be transferred to SystemVue for further processing and for use in simulations.

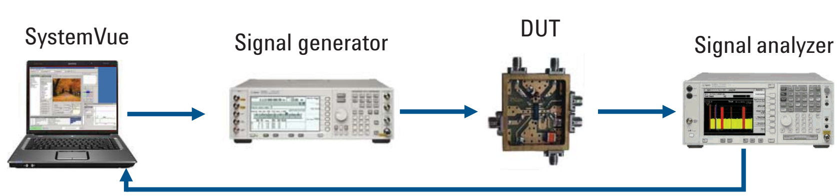


Figure 16. A combination of software and instrumentation can be used to create and generate radar test signals

When surrounded by appropriate stimulus/response instrumentation, this type of simulation platform can be used to manually imitate missing hardware blocks and thereby simulate a working radar system. This enables system-level validation earlier in the development process, even when working with partially implemented hardware. As real hardware becomes available, the simulation platform is easily refocused on the task of providing targeted radar signals for the instrumentation to use in testing.

The SystemVue platform provides an interface to a range of test equipment to help verify the implemented hardware. Examples include signal analyzers such as the N9030A PXA, logic analyzers such as the 16800 series and oscilloscopes such as the enAgilent Infiniium 90000 X-Series. SystemVue also supports signal generation for wideband baseband arbitrary waveform generators such as the Agilent N6030A, M9330A, and 81180. SystemVue and the W1905 library can also be connected to the Agilent 89600B vector signal analysis (VSA) software. Designed for the engineering environment, the 89600B software provides advanced general-purpose and standards-based tools for measuring signal characteristics in the time, frequency and modulation domains. The software can run on a PC or inside certain Agilent signal analyzers, logic analyzers and scopes.

In all, these capabilities help designers save time and reduce costs as they assess algorithm robustness, create highly realistic test signals and analyze overall system performance. Time savings come from the ability to quickly model a radar system and verify algorithms prior to implementation of targeted hardware. Cost savings stem from the ability to use the synthetic range approach early in the development process rather than relying on expensive hardware simulators or costly field testing later in the process when it is more difficult, costly and time-consuming to make changes.

Validation and Analysis of Radar Signals

Radar pulse analysis has become much more challenging as manufacturers have embraced compression technology to improve resolution and range while reducing ambiguity. This places unique demands on the analysis equipment for larger bandwidths and more complex multi-domain displays.

In addition to the growing necessity of modulation analysis for compressed pulses, the radar industry is increasingly moving to software-defined radar architectures in which the stability and flexibility of digital implementations is rapidly replacing traditional analog IF and baseband signal processing. This too creates special test challenges as the format and access to signals changes radically from baseband to RF.

Agilent analysis tools

To meet these challenges Agilent has created a broad array of analysis instruments that provides the performance and flexibility to view virtually all radar signals across a wide variety of signal formats.

To meet the different needs in price and performance, Agilent offers four bench signal/spectrum analyzer lines plus a portable analyzer line: the PXA performance analyzer offers industry leading modulation bandwidth (140 MHz) and SFDR (78 dB); the MXA offers good performance with reduced price; the EXA and CXA offer economy. The portable line is suitable for many installation and maintenance applications. These analyzers are excellent choices for everything from cutting-edge applications to routine low-cost measurements.

Figure 17. Agilent signal analyzer product family

In keeping with Agilent's offerings at a variety of price points, the 89601B vector signal analysis (VSA) software can be added to most of the above analyzers. The ability to add the 89601B addresses the need for modulation-domain measurements on compressed pulses. The 89601B VSA thus allows data captured on the signal analyzers to be displayed in a wide variety of modulation domains.

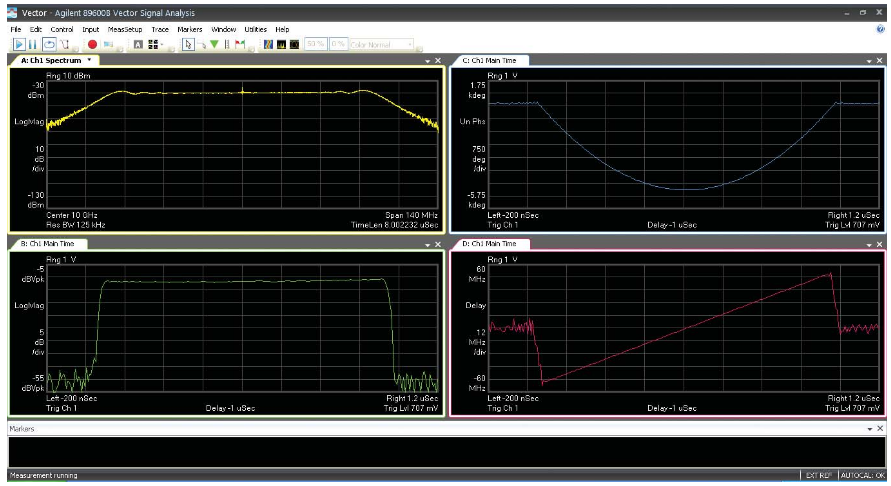


Figure 18. Viewing a chirp pulse with the 89601B VSA software

To illustrate the capabilities of Agilent analysis instruments, let’s look at some example measurements. We will begin with common radar signal measurements, followed by a more difficult signal-quality measurement and finally look at Agilent’s unique software-defined radar measurement capability

Pulse analysis

Radar, EW and ELINT engineers make a variety of routine measurements. As highlighted earlier, pulse width and PRF or PRI provide important information about a radar system’s resolution and range, as well as potentially important intelligence information. Automated measurement of these parameters can greatly speed radar diagnostics and provide a wealth of EW information.

Using an Agilent signal analyzer or oscilloscope and the N9051A signal analysis software, quick automated measurements are possible, speeding the engineer’s time-to-insight for routine measurements of more than 15 common pulse parameters. One nice feature of the N9051A pulse analysis software is that it automatically configures the signal analyzer or oscilloscope to optimize the settings for maximum instrument accuracy.

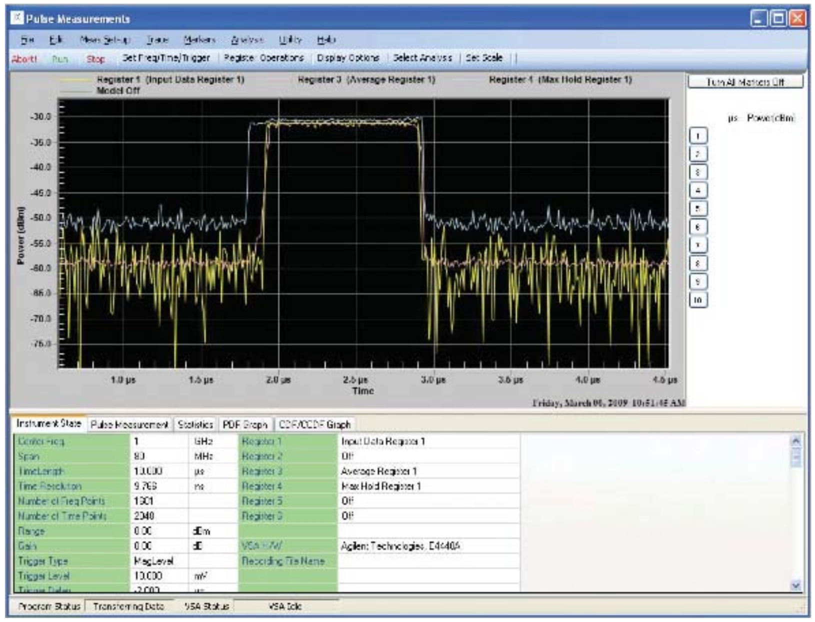


Figure 19. Agilent N9051A pulse analysis software

Multi-format modulation analysis with the 89601B software

The software-defined radar architecture poses unique challenges for test as the signal format changes from the familiar coaxial analog microwave transmission line to the digital bus often buried deep within an FPGA. Such mixed digital and analog design implementations pose the problem of being able to perform advanced modulated pulse analysis, as shown in the previous example, on vastly different signal formats but with consistent measurement results.

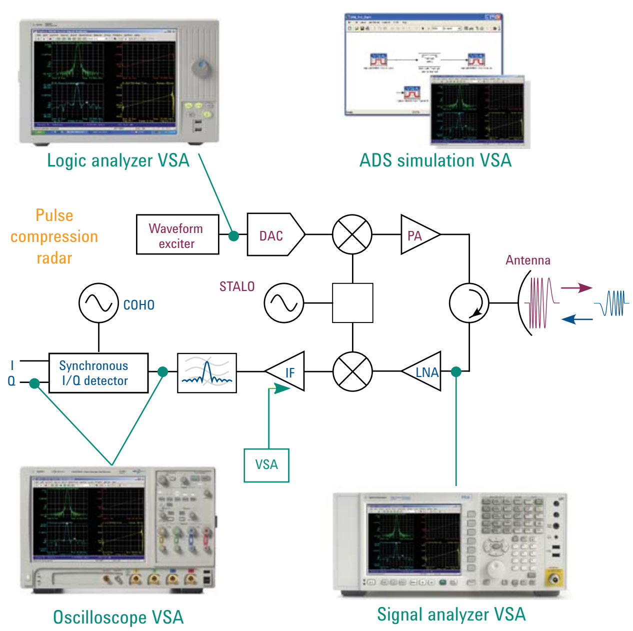


Figure 20. Multi-format 89601B VSA analysis

The 89601B VSA is uniquely capable of interfacing with a variety of measurement instruments. For example, the 89601B software can use Agilent signal analyzers, Infiniium oscilloscopes and 16800 logic analyzers as a front end to the software VSA. In addition, the 89601B is compatible with Agilent's Advanced Design System (ADS) circuit modeling software. Not only does this simplify the process of learning how to make instrument-based measurements, it also guarantees consistency between measurements because the same VSA software algorithms are used regardless of the format of the signal being measured (digital or analog).

Another unique benefit of the 89601B VSA with the 16800 logic analyzer front end is the ability to use the Agilent ATC2 FPGA design core. The ATC2 design core allows for seamless access to supported FPGA internal data busses (for Xilinx and Altera FPGAs), enabling sophisticated VSA signal analysis directly on real-time FPGA design implementations.

The 89601B VSA is also compatible with the Agilent PXA, enabling a high performance interface on traditional coaxial microwave transmission lines as well as the Infiniium oscilloscopes with analysis bandwidths up to 32 GHz.

Time side lobe level measurements

Basic pulse analysis can yield a wealth of information about a radar's general performance; however, for more complicated compressed pulses a more sophisticated measurement capability is needed to characterize the resolution capability of the radar. One such measurement is the time side lobe level (SLL), which provides a general quality metric of a received linear frequency modulated (LFM) chirp. SLL looks at the side lobe levels after the received correlation filter and compares them to a mathematically perfect receiver. Magnitude, phase, FM and group delay errors will raise the side lobe level from the compressed pulse and lower the resolution capability of the radar.

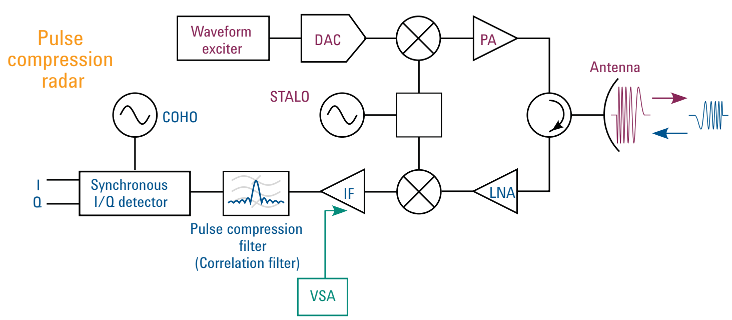


Figure 21. Pulse compression radar and the time SLL measurement

The quality factor time SLL is usually measured by illuminating a reference radar target, and quantifying the side lobe levels at the radar receiver's pulse compression filter output.

The Agilent 89601B VSA can perform the compression filter function in that it correlates or compares the transmitter output signal to a mathematically correct waveform. Using MATLAB code, a mathematically perfect compressed pulse waveform can be created. Creating a reference waveform requires knowledge of the important parameters of the signal to be measured such as FM bandwidth, pulse width, and sample rate of the VSA during the measurement. Using this information, and an Agilent VSA, the time SLL measurement can accurately show the clarity of the returned echo and how well the pulse shape remained intact.

Conclusions

Evolving trends in radar & EW test

Modern radars continue to grow in complexity while moving more functionality into the digital subsystem.

Radar signal creation

On the signal synthesis side, Agilent provides a complete line of microwave sources and arbitrary waveform generators for test and development. Agilent's line of signal generators is supported by Signal Studio for Pulse Building, which easily generates a wide variety of compressed and non-compressed pulse patterns. Signal Studio for Pulse Building II also supports antenna patterns with the ability to modulate pulse amplitude based on a variety of scanning antenna patterns.

Not only are these source features ideal for modern radar testing but they are also excellent for creating a synthetic laboratory test range that can save large sums of money over field-testing operations as prices for field testing climb.

EW analysis tools

When it comes to analysis of radar signals, Agilent offers a variety of products and product features tailored to the radar, EW and ELINT engineer's needs. Products such as the Agilent PXA signal analyzer offer industry-leading performance in analysis bandwidth and dynamic range. Likewise, for routine radar measurements, Agilent's pulse-analysis software provides quick and easy data acquisition across the signal analyzer product line from high performance to economy instruments.

The ubiquitous shift toward compressed pulses and software-defined radar architectures is supported by the Agilent 89601B VSA. The 89601B software offers tremendous flexibility in measuring compressed pulses, supporting modulations from simple LFM chirps to complex phase-modulated pulses.

The 89601B VSA software is also supported by a wide range of instruments ideal for radar and EW applications, ranging from 16800 logic analyzers to Infiniium oscilloscopes to PXA signal analyzers. The 89601B VSA software easily interfaces with Agilent's Advanced Design System (ADS), allowing simulation and analysis of yet-to-be-built designs. This wide range of radar signal analysis formats is ideal for today's competitive software-defined radar architectures.

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