Radar, Electronic Warfare, and Electronic Intelligence Testing: Identifying Common Test Challenges

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Published in USA, November 1, 2012
5991-1368EN

This article first appeared in the
August 2012 issue of Defense Tech Briefs.

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Radar, Electronic Warfare, and Electronic Intelligence Testing:

Identifying Common Test Challenges

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).

Regardless of complexity, radar, EW, and ELINT systems share many common test 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 retransmit 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.

Primary radars suffer significant signal

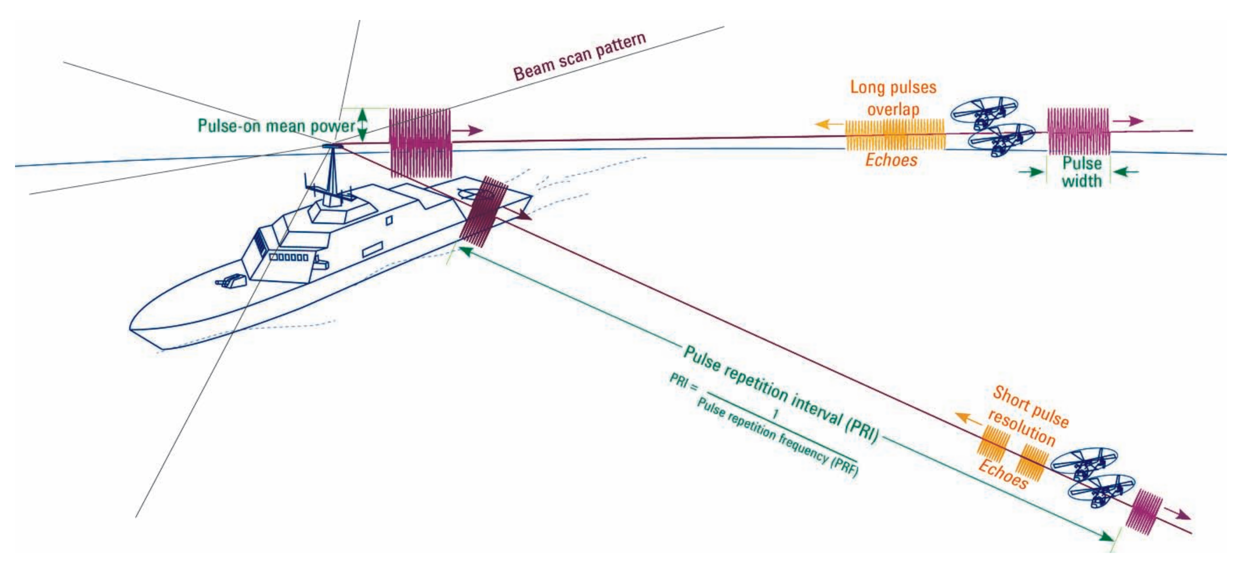

Figure 1. Radar pulse terminology and tradeoffs.

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.

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.

Pulse compression or modulation offers other advantages in unambiguous range. To see these advantages, 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.

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.

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.

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.

Modern Radar and EW Test Challenges

Testing modern radar systems places unique demands on test and measurement equipment. 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.

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.

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 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.

Common Test Challenges

Arbitrary Waveform Generators and 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.

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.

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 addition to the number of bits and inherent sampling function loss of SFDR, up-conversion 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 up-conversion from the baseband arbitrary waveform generator's DAC.

This up-conversion can either be performed internally by the signal source or externally with a separate device. Simple in concept, it would seem easy to up-convert 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.

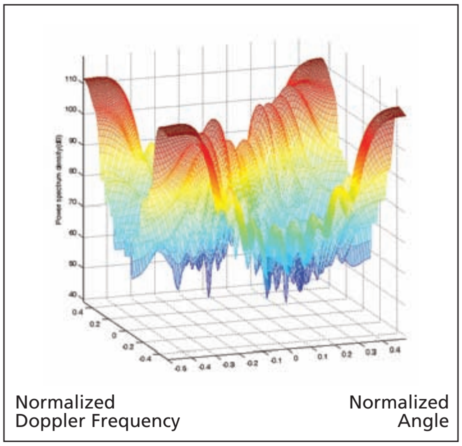

Figure 2. Agilent's SystemVue software was used to analyze pulsed Doppler target returns in this scenario with clutter models. MATLAB integration within SystemVue allows this result to be visualized in 3D.

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 up-converters for signal bandwidths less than 2 GHz, instead opting to purchase a microwave source with the arbitrary waveform generator and up-conversion hardware built in. This is particularly true if phase noise is important to the measurement application.

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.

As mentioned earlier, 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.

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 also creates special test challenges as the format and access to signals changes radically from baseband to RF.

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.

This article was written by John Hansen, Senior Application Engineer, at Agilent Technologies, Santa Clara, CA.

Reprinted from Defense Tech Briefs, August 2012. On the web at www.techbriefs.com.